THE GLASS INDUSTRY

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# ANALYSIS OF STRAINS AND STRESS IN GLASS
## I—POLARIZED LIGHT AND POLARISCOPES

By A. J. MONACK and E. E. BEETON
WESTERN ELECTRIC COMPANY, INC.
VACUUM TUBE SHOP

All workers with glass become interested at some time in the process of annealing. But, with the exception of the optical glass industry, there are no quantitative standards of annealing and the glass is usually said to be "well annealed," "satisfactorily annealed," or "poorly annealed." The dividing lines that separate the different degrees are entirely arbitrary and do not have the same meaning when applied to various types of glassware. For instance, a degree of annealing that is satisfactory in the container industry would be considered poor annealing when applied to optical glass. Approaching from a different angle, the benefits derived from annealing a bottle to the same level of residual strain as optical glass would not be in proportion to the costs of such added annealing, since the reduction of strain very far below a safe limit is governed by a law of diminishing returns. Yet strain is a problem of importance in every branch of the glass industry.

The efficiency of any annealing schedule is determined by the amount of residual stress in the glass. The words "stress" and "strain" are generally used interchangeably. Actually, stress is a force per unit area and strain is a deformation. Within the proportional limit, however, the unit stress at any point is proportional to the unit strain, since from Hooke's law, stress divided by strain equals a constant, this constant being the modulus of elasticity. Optical effects are caused by the strain.

The nature and amount of strain in glass is determined by viewing it in a polariscope and, when glass is observed in the usual type of polariscope, any strains present are seen as colored areas in the glass article. In order to evaluate properly the image seen in a polariscope, it is necessary to have a reasonably thorough understanding of polarized light and of the laws which govern its behavior in passing through stressed and unstressed glass.

### FOREWORD

**This article is the first of a series, which THE GLASS INDUSTRY is pleased to present to its readers in the interest of a better general understanding of a very important, though highly technical, phase in glass manufacture. Most of the material given here has been previously published, but previous presentations have included all of the scientific and mathematical data, necessary for a complete understanding of the subject, but relatively unimportant for practical conception and use. After long and careful preparation, these able authors have successfully presented, in an understandable manner and every-day engineering language, as much of the theory of optics, optical mineralogy, and photoelasticity as is necessary for an understanding of the phenomena involved when strained glass is analyzed by means of polarized light. Fundamental laws governing the production and use of polarized light are reviewed and various types of polariscopes are discussed briefly. Succeeding articles will take up in some detail the analysis of mechanically-induced stresses in glass of simple shapes. Finally, the methods for analyzing stresses, both mechanical and thermal, in more complicated shapes will be treated.**

The nature of polarized light can best be understood by considering some simple experiments, in which use is made of the polarizing film that has recently made its appearance on the market. If a sheet of white paper is observed through a sheet of polarizing film, the paper appears slightly colored due to the coloration of the film, and that is all that the eye can tell. Furthermore, if two similar films are placed face to face with their axes parallel, as in Fig. 1a, the only observable difference produced is an increase in the coloration of the emergent light, and the rotation of both films together in a plane parallel with their faces produces no difference in the appearance of the combination. If, on the other hand, one film is rotated with respect to the other, Fig. 1b, the light transmitted through the two becomes fainter and fainter until, when the axes of the films are at right angles, the light is totally extinguished, as shown in Fig. 1c, and nothing can be seen through them. In this position the films are said to be crossed. If the film is now further rotated, so that the angle between the axes is made greater than 90°, more and more light is transmitted as the angle is increased. Finally, after the film has been rotated through 180°, the same amount of light emerges as in the original position and the white paper looks just as it did at the start.

It is evident that this film has certain properties that enable it to change a light ray passing through it, so that the light acquires a one-sidedness with regard to the direction of the ray. In other words, the film transmits rays vibrating only in one direction, and if the axis of the second film is parallel to that of the first, the waves transmitted by the first film can pass through the second film also. If, however, the axes of the two films are at right angles to each other, no light can pass through the second film because the light transmitted by the first film consists of vibrations in a direction at right

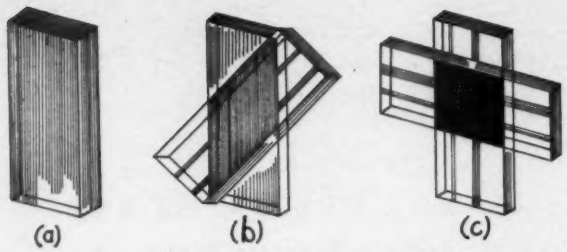



**Fig. 1. Light transmission through polarizing film. (a) Maximum transmission with axes parallel; (b) Partial transmission with axes at an angle; (c) Minimum transmission with axes crossed.**

angles to that at which it can be transmitted by the second film, as indicated in Fig. 2. Light rays which have acquired this one-sidedness are said to be *plane polarized*.

The polarizing ability of this type of film lies in the circumstance that the film consists of a suspension of synthetic organic iodine crystals in a cellulosic matrix, all the crystals being in substantially uniform orientation or direction. The film is made in various thicknesses, but it is usually from 0.001 to 0.004 in. thick. As the thickness of the film is increased the transmission decreases and the degree of polarization of the transmitted light increases. The film is mounted between sheets of glass in order to give it stiffness and to protect it from damage.

The individual crystals in the film are so small that, at a magnification of 1,100 and with polarized illumination, it is just possible to discern discontinuities in the film. The crystals are in the form of needles whose diameter is considerably less than the wave-length of visible light and, when light enters one of these crystals, it is divided into two components polarized at right angles to each other. One of these components is more strongly absorbed than the other. More will be said about the mechanism of the polarization of light by these films after polarization by double refraction has been covered.

### Polarization by Reflection

Light may be polarized by other means than passing it through a polarizing film. For instance, it may be polarized more or less completely by reflection, at a suitable angle, from the surface of a transparent medium, such as a plate of glass. When ordinary light, which is vibrating in all directions at right angles to its path, strikes the surface of a transparent medium obliquely, it is divided into a reflected and a refracted ray, both of which are partially polarized. Those vibrations of the incident light which are most nearly perpendicular to the surface of the medium penetrate it most easily, while those vibrations which are most nearly parallel to the same surface are practically all reflected. Those vibrations which strike the surface at an angle between 0° and 90° are more-or-less completely resolved into two components, one of which vibrates parallel to the surface and is reflected, while the other vibrates at right angles to the first and is refracted. The amount of the incident light which is polarized in this way varies with the angle of incidence. It is none at all for normal incidence, and the amount increases to practically all the light, when the angle whose tangent is equal to the index of refraction of the polarizing medium is reached.

These relationships can be better understood by reference to Fig. 3. Here the incident ray AO is vibrating in all directions normal to the ray and upon striking the surface of the new medium BC at the angle which gives complete polarization, it is divided into a reflected ray OD, which vibrates parallel to the surface and normal to the ray, and a refracted ray OE, which vibrates at right angles to OD and normal to the ray.

Drawings such as Fig. 3 are often misleading, because they show only a single ray of light, something which is never dealt with in practice. Reference to Fig. 3 shows no reason why the reflected light should not be completely polarized, but there are at least two reasons, the first of which concerns the nature of white light. Theoretically, the tangent of the angle of incidence must equal the index of refraction of the reflecting medium for complete polarization, but the index of refraction varies with the wave-length of the light used for its determination. Consequently, the polarizing angle would have a different value for red light than for violet light and, since white light is composed of light of all wave lengths between those corresponding to red and violet, it is impossible for a single angle to satisfy all the conditions, and all the light can never strike the plane surface at the optimum angle. This condition can be satisfied by using monochromatic[1] light, which is not always desirable, but still all the rays must strike the reflecting surface at the same angle. Since it is impossible to utilize a point source of light for illumination, any lens used to render the light parallel can only approximate true parallelism of the rays, and again all the rays will not strike the reflecting surface at the optimum angle. It is evident, therefore, that light can not be polarized 100 per cent by reflection from a transparent surface.

Polarization by reflection has been covered in some detail because many of the definitions used in describing polarized light are based on this method. Referring again to Fig. 3, the plane containing the lines AO, OF, and OD is called the plane of incidence. The ray of light OD is said to be polarized in the plane of incidence, although the vibration direction is at right angles to the plane of incidence. In other words, the light waves

[1]Monochromatic light is light of only one wave-length, but for practical purposes a small variation on each side of this wave-length may be permitted. Monochromatic light may be produced (1) by placing common salt (light with wave-length of 589 mμ), lithium salts (671 mμ), thallium salts (536 mμ) in a Bunsen flame; (2) by the use of a mercury arc lamp (two wave-lengths, 546 and 436 mμ, one of which must be absorbed by a filter); and (3) by passing white light through a filter such as Wratten No. 62 (530 mμ). A strong source of light must be used in the third case because of absorption by the filter.

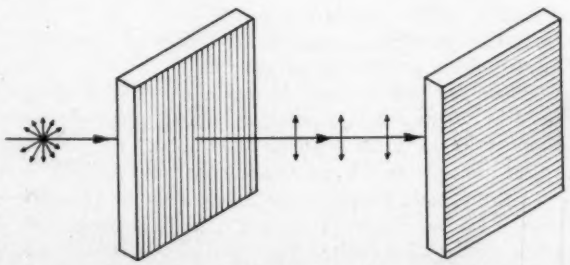


**Fig. 2. Effect of crossed polarizing films on vibrations of white light.**

in a polarized ray are vibrating in a direction at right angles to the plane of polarization. In what is to follow, however, only the direction of vibration will be considered and the plane of polarization will be disregarded. The angle of incidence, whose tangent must equal the index of refraction of the polarizing medium for maximum polarization of the reflected ray, is defined as the angle AOF which the incident ray makes with the normal to the surface. When ordinary glass is used for the reflecting surface the angle of incidence is about 57 degrees.

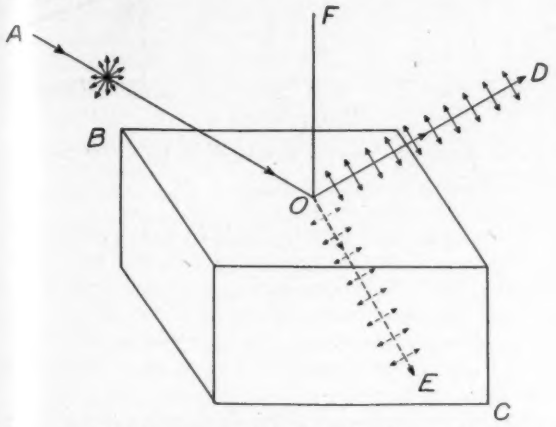



**Fig. 3. Polarization of light by reflection and refraction from a transparent body.**

The presence of polarization in light reflected from any surface can, of course, be detected by causing the reflected light to pass through a polarizing film before reaching the eye. If any change in the intensity of the transmitted light is then produced by rotation of the film about the ray as an axis, partial polarization of the ray is indicated; if the film, in any position, extinguishes the light, it is evident that the ray has been completely polarized. This gives a rough means of determining the amount of polarization of any light. In these cases the film is used to analyze the light, and it is called an *analyzer*. When the light reflected from the surface of water, glass, polished paint or lacquer, and many other surfaces, is analyzed thus with a polarizing film, more or less variation in the brightness of the transmitted light occurs, showing that the reflected light is at least partially polarized.

In practice, when a plane reflecting surface is used as a polarizer, it is best to use a sheet of black glass, or a sheet of clear glass with the under side painted black. Either of these will absorb the refracted ray and thus avoid extraneous reflections.

### Polarization by Double Refraction

As mentioned in the discussion of polarizing film, light can also be polarized by double refraction. Certain crystals have the ability to break up light falling on them into two rays which are polarized at right angles to each other. These polarized rays travel at different velocities along different paths through the crystal. This division of the light into two rays is called double refraction, and the ability of a crystal to separate the two refracted rays is known as its birefringence. Only a few crystals have sufficiently strong birefringence to make the double refraction easily visible to the naked eye.

If an illuminated pinhole is viewed through a cleavage section of clear calcite, two images of the pinhole can be seen, and upon rotation of the calcite, one image remains stationary while the other revolves about it. The light which produces the fixed image is called the ordinary ray or O ray, since it travels through the calcite just as it would through a piece of unstrained glass. The light which produces the movable image is called the extraordinary ray, or E ray, since it does not travel through the calcite as it would through glass. The paths of the two rays of light through the calcite are shown in Fig. 4, in which A is the pinhole, B is the fixed image produced by the O ray, and C is the image produced by the E ray, which revolves about B as the crystal is rotated. The two images have equal illumination, but they are not at the same distance from the surface of the calcite. The O ray strikes each surface of the mineral at right angles and passes straight through. Although all of the incident light is normal to the lower surface, part of it is refracted to form the E ray, which strikes the upper surface at an acute angle, but nevertheless leaves the crystal at right angles to the surface. In short, the E ray is truly extraordinary in its apparent defiance of the law of refraction at each surface.

These two rays are completely polarized, so that each is vibrating in only one plane, the E ray in the plane of the paper and the O ray perpendicular to the paper in Fig. 4, all vibrations being at right angles to the path

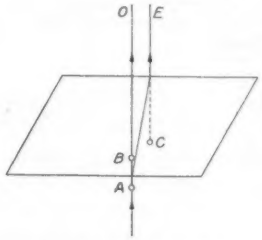



**Fig. 4. Double refraction of light into ordinary and extraordinary rays by means of a crystal of calcite.**

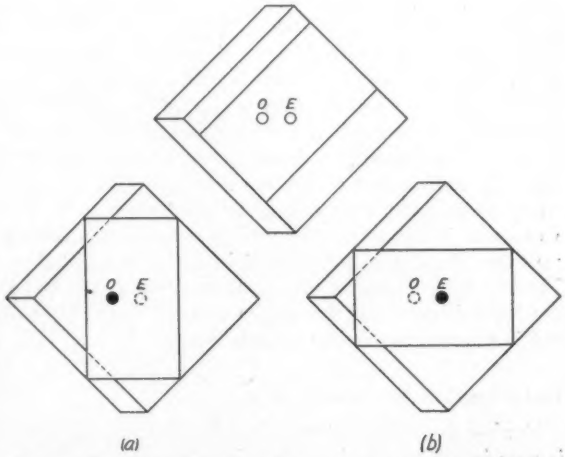



**Fig. 5. Polarization at right angles of ordinary and extraordinary rays in calcite shown by inspection through polarizing films.**

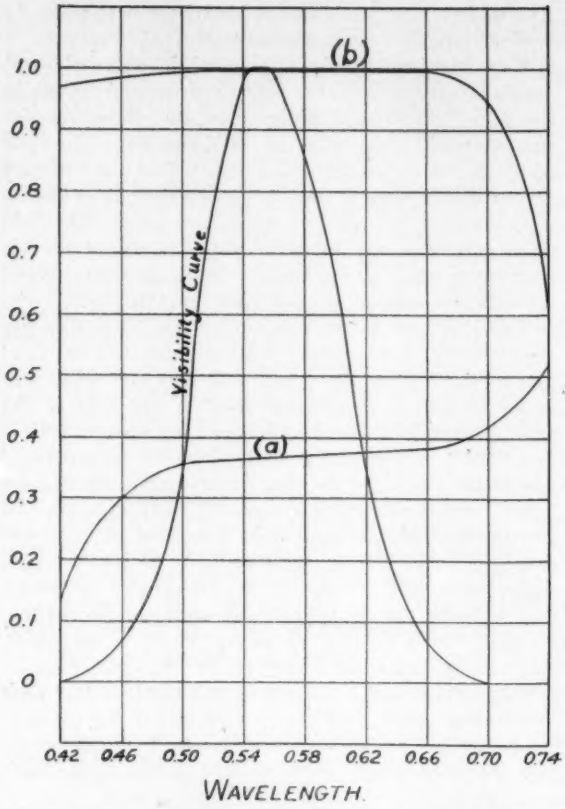



**Fig. 6. Curves showing transmission and polarization of Polaroid at different wave-lengths, as compared with visibility curve (Grabau).**

of the ray. These facts may be verified by the use of polarizing film, since it has already been shown that such a film can be used as an analyzer for polarized light. If such a polarizing film is placed over the calcite, with its axis parallel to the long diagonal of the rhombic face of the calcite, only the image produced by the O ray is visible, as in Fig. 5a. If the film is then turned through 45°, both images are visible and of equal intensity, although the intensity is less than it would be without the film. If the film is finally turned 90° from its original position, only the image due to the E ray is visible, as in Fig. 5b. It has already been shown that light which is transmitted through a polarizing film in one position, and intercepted when the film is rotated through 90°, is polarized. Consequently, the rays that produce the ordinary and extraordinary images must be polarized and, since the extraordinary rays are intercepted by the film when the ordinary rays are most freely transmitted, and vice versa, it follows that the ordinary and extraordinary rays are vibrating in planes at right angles to each other. Therefore, the ordinary ray is vibrating in the plane of the long diagonal of the calcite and the extraordinary ray is vibrating at right angles to it.

### Polarization by Absorption

Further discussion of the polarization of light by films is now in order. A sheet of polarizing film can be regarded as a three-dimensional system of oriented crystals, closely packed together in the film. Each one

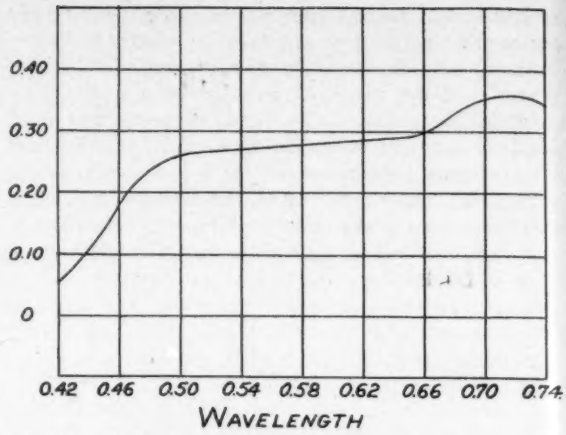



**Fig. 7. Transmission of Polaroid films with axes parallel (Grabau).**

of these tiny crystals polarizes light by double refraction, but the crystal absorbs one of the polarized rays more than the other. This is dichroism. Since the crystals are so small that the thinnest polarizing film contains many layers, selective absorption takes place, and one of the two polarized rays is transmitted much more freely than the other.

Grabau[2] has published some data on commercial Polaroid[3] as of July, 1937, and his curves are reproduced in Figs. 6, 7, and 8. Fig. 6a gives the spectral transmission; Fig. 6b shows the spectral distribution of the degree of polarization. These are compared with a full-scale representation of the visibility curve. Fig. 7 gives the transmission of two pieces of Polaroid with their axes parallel, and Fig. 8 shows the transmission when the axes are crossed. These curves indicate the excellent polarizing properties of this material very forcibly.

### The Nicol prism

No description of polarized light would be complete without a discussion of the Nicol prism, because it gives the ultimate in polarization by double refraction. In precision optical instruments a Nicol prism, or one of its variations, is always used for both polarizer and analyzer and there is good reason for this, since no other type of polarizer produces polarized light of the same degree of purity. The light reflected from a glass plate always contains some unpolarized light. The polarizing films color the transmitted light slightly and, when crossed, transmit some unpolarized light in the violet region of the spectrum. Since the Nicol prism forms at least a part of many polariscopes and allied optical instruments, it will be considered in some detail.

In Fig. 9a, ABCD is the isometric projection of a long crystal of Iceland spar, of which B and D are the obtuse solid angles, each contained by three obtuse plane angles. An imaginary plane drawn through the blunt edges BC and AD contains the optic axis of the crystal and this plane may be termed the principal section of the crystal. A ray incident on the face AB, in a plane parallel to the

[2]M. Grabau, "The Optical Properties of Polaroid for Visible Light," *J. Optical Soc. Amer.*, 27, 420 (1937).

[3]Registered trade-name of a material manufactured and sold under (E. H. Land) U.S. Patents 1,918,848; 1,989,371; 1,951,664; 1,956,867; 2,011,553.

principal section, gives rise to an ordinary and an extraordinary ray, both of which lie in the plane of incidence. These rays travel with different velocities, that of the extraordinary ray being the greater.

The refractive index of Canada balsam is equal to 1.55, which is a value intermediate between the ordinary and extraordinary refractive indices of Iceland spar. Consequently, the velocity of wave transmission in Canada balsam is greater than the ordinary, and less than the extraordinary, velocity of wave transmission in the spar. If the ordinary ray in the spar is incident on a layer of Canada balsam it will be totally reflected when the angle of incidence is greater than a certain critical value. On the other hand, the extraordinary ray cannot be totally reflected under similar conditions, since its velocity in the balsam is less than in the spar. Thus, by allowing the ordinary and extraordinary rays, traveling through Iceland spar, to fall at a suitable angle on a layer of Canada balsam, the ordinary ray can be reflected to one side and eliminated, while the extraordinary ray is transmitted. This is the principle of construction and operation of the Nicol prism.

The natural end faces AB and DC, Fig. 9a, of a crystal of Iceland spar are inclined at about 71° to the blunt edges AD and BC, respectively. In constructing a Nicol prism the ends of the crystal are first cut perpendicular to the principal section, so as to form new end faces AE and CF inclined at about 68° to the edges AF and EC, respectively. The prism is then divided into two parts by a diagonal cut EGF, perpendicular to the principal section and also perpendicular to the end faces AE and CF. The diagonal cut surfaces are then ground plane, polished, and cemented together by a film of Canada balsam. The prism is then complete and is mounted in a brass tube to protect the spar from injury.

The section of a Nicol prism produced by a plane passing through the opposite blunt edges EC and AF is shown in Fig. 9b, and the film of balsam is represented by EF. A ray HK, incident in the plane of the paper on the end face AE, is divided into an ordinary ray KO and an extraordinary ray KM, within the prism. The ordinary ray is totally reflected at O from the film of balsam, while the extraordinary ray is transmitted through the prism and leaves the face FC parallel to the direction HK of the incident ray. Thus, a ray of pure polarized light of considerable intensity is obtained and, since the vibrations in the extraordinary ray are in the principal plane, it follows that the vibrations in the ray MN will be parallel to the plane of the paper. As shown in the end view of a Nicol prism, Fig. 9c, the direction of vibration of the transmitted light is parallel to the shorter diagonal of the end face, as indicated by the direction of the double arrow.

A Nicol prism (often termed, for brevity, a nicol) can be used either as a polarizer or an analyzer. When two nicols are placed end to end, with their principal sections parallel, the light transmitted through one is also transmitted through the other. If one of the nicols is then rotated, the transmission of light gradually becomes feebler, the intensity of the transmitted light being proportional to the square of the cosine of the angle between the principal sections of the two nicols. When the principal sections are perpendicular to each other no light is transmitted, because the extraordinary ray from the first

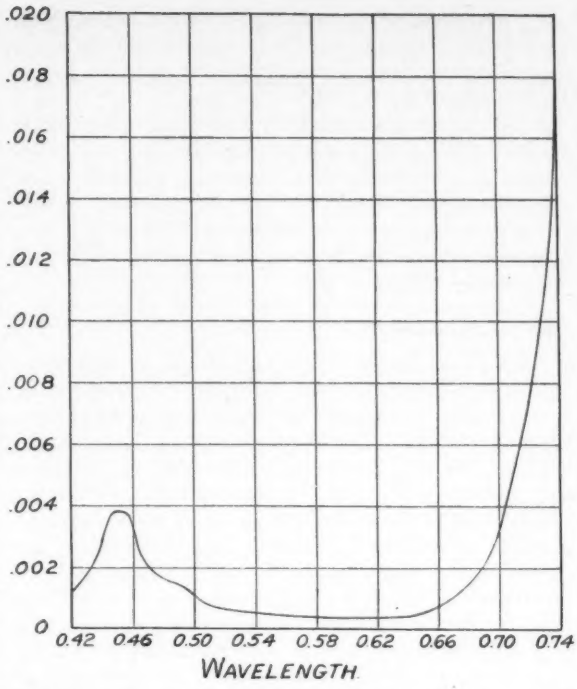



**Fig. 8. Transmission of Polaroid films with axes crossed (Grabau).**

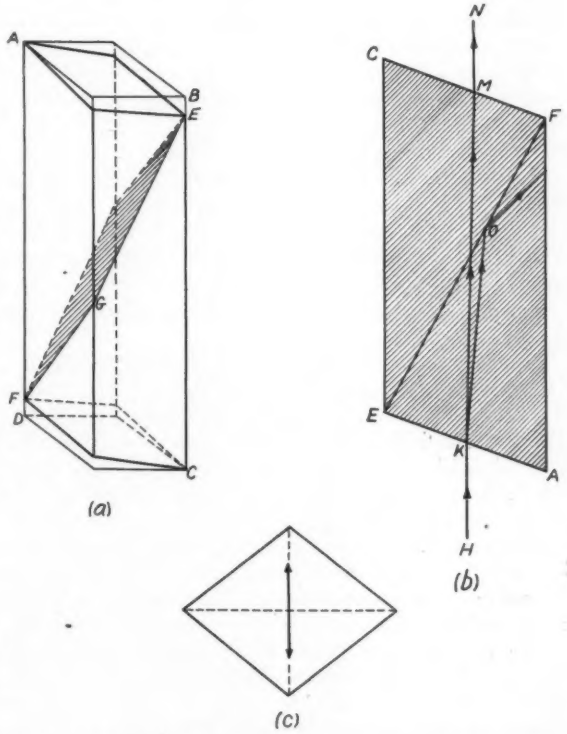



**Fig. 9. The Nicol prism. (a) Construction of the prism showing the diagonal layer of Canada balsam; (b) Diagrammatic section showing reflection of ordinary ray by the film of Canada balsam; (c) Direction of vibration of the polarized extraordinary ray as it leaves the prism.**

nicol forms an ordinary ray in the second and is, therefore, totally reflected from the balsam. When the nicols are arranged with their principal sections perpendicular to each other they are said to be crossed.

Nicol prisms are sometimes made with the rhombic vertical edges ground off, so that the diagonal cross-section is a rectangle whose sides are parallel to the diagonals of the rhomb, and the end faces are usually at right angles to the vertical edges. Such prisms may be made much shorter, in proportion to their width, than the ordinary type of nicol.

**The polariscope**

Glass is examined in a polariscope to determine whether or not it is strained, the simplest type of polariscope consisting of a polarizer and analyzer. Any device that will polarize light can be used as a polarizer or an analyzer, the only requirement being that the polarizer and analyzer be "crossed." In other words, the direction of vibration in the analyzer must be at right angles to that in the polarizer. The two polarizing films, described earlier when studying polarized light, make a satisfactory polariscope when arranged as in Fig. 1c or Fig. 2. This combination, together with a sensitive tint plate, of which more will be said later, forms the basis of several commercial polariscopes. Another type of commercial polariscope uses a Nicol prism for the analyzer and polarizes the light by reflection from a curved plate, the curved plate being used so that a greater percentage of the parallel incident light will strike the reflecting plate at the optimum polarizing angle. Other types use flat glass reflecting plates. The varieties are too numerous to mention, but each one consists essentially of a polarizer and an analyzer, no matter what form it may take. Some polariscopes have a built-in light source and some do not. It is preferable to have the light source an integral part of the instrument, because the manufacturer can then design the whole optical system so that it will function efficiently. Also, the strain colors seen in the polariscopes are affected by the intensity of the light, and a light-source which is an integral part of the instrument assures that all observations are made under similar light conditions.

(*In the May issue, polarized light in strained glass will be discussed.*)

## SAINT PAT AT ALFRED

For the seventh time, the birthday of Saint Patrick, patron of bricklayers and engineers, was celebrated at the N. Y. State College of Ceramics in a two-day festival. A parade with competing floats depicting progress in ceramics and glass, an assembly at which Ray Buckley enacted the Saint's role and ribbed the faculty; and several social events occupied Thursday and Friday afternoons and evenings.

The outstanding event of the festival was the Open House on Thursday evening. Skilled glassworkers from Corning demonstrated the blowing of off-hand ware from a small tank of crystal glass. Exhibits of glass products, a fiber-drawing machine, a model tank, samples and charts of raw materials, strain-viewers, and demonstrations of the strength and elasticity of glass also entertained the thousand or so visitors. Other departments of the college were also open for inspection, the spectroscopy laboratory having an especially interesting show.

Several visiting ceramists, as well as 34 seniors in the college, were made Knights of Saint Patrick. Kruzen, Knapp and Diamond added this distinction to their ceramic honors.

## FORD MOTOR GLASS EXECUTIVE DIES

Arne T. Nelson, Assistant Superintendent of the glass plant of the Ford Motor Co., Dearborn, Mich., died suddenly in February while at work. Mr. Nelson entered the employ of the Ford Motor Co. in 1927, designed some of the machinery for the glass plant, and upon completion of the plant was named assistant superintendent. Born in Tonsberg, Norway, Oct. 23, 1878, he was educated in London, England, and Newark, N. J., after which he learned tool making in New York and went to Detroit in 1904 as tool maker for the Cadillac Motor Car Co. From that time Mr. Nelson functioned for many years as a machine designer in the automotive industry and had been in the real estate business for a time when he joined the Ford organization. The Ford glass plant is probably more highly mechanized than any other flat glass plant in the world and Mr. Nelson played a large part in its design and operation.

## HENRY J. BATSCH, 1863-1939

It is with regret that THE GLASS INDUSTRY records the death on March 13th of Henry J. Batsch, vice-president of the Indiana Glass Company of Dunkirk, Ind. Mr. Batsch had a long and distinguished career in the glass industry beginning at the youthful age of seven when he learned his trade at the Hobbs Glass Co. in Wheeling. Later he worked in Moundsville, W. Va., and was with the Dalzell, Gilmore and Lighting Glass Co. as a presser, night foreman and as day manager. He was later connected with the Nivison-Wescoff Glass Co., and the National Glass Co., before joining the Indiana Glass Co. as manager, where he has been associated for the past 35 years.

## PRODUCTION FIGURES FOR THE GLASS INDUSTRY DURING FEBRUARY

**Glass Containers:** Production of glass containers during the month of February, 1939, was 3,389,281 gross, bringing the 1939 total to 6,987,444 gross. Shipments during February were 3,323,188 gross, bringing the 1939 total to 6,976,321 gross.

**Window Glass:** During February, 1939, the production of window glass was 808,585 boxes which represents 49.8 per cent of industry capacity. As compared with this, February, 1938, production was 537,023 boxes, representing 39.5 per cent of industry capacity.

**Plate Glass:** The production of plate glass by member companies of the Plate Glass Manufacturers of America during February, 1939, was 10,165,401 sq. ft., as compared to 12,209,080 sq. ft., produced in the preceding month, January, 1939, and 2,663,835 sq. ft., produced in February, 1938.

• Word has been received that the Third International Congress on Glass scheduled for Berlin and Munich, Germany, in July, 1939, has been postponed until 1940.

# FINE PROGRAM ATTRACTS GLASS DIVISION MEMBERS

**Completed program for the 41st Annual Meeting of the American Ceramic Society in Chicago, April 16-21, includes a profusion of papers of interest and value to glass technologists and engineers.**

As final plans for the 41st Annual Meeting of the American Ceramic Society at the Stevens Hotel in Chicago reach completion, it is apparent that the members of the Glass Division will take part in a program of greater than usual scope and interest. Not only in the Glass Division sessions themselves, but also in other sections of the meeting, the technical men of the glass industry will have to watch their time schedules carefully if they are to take advantage of all the new and exciting information that will be available for them.

Although the glass world is always well represented at the annual meetings of the Society, it seems quite apparent that the features of the coming meeting in Chicago will attract the active participation of an outstanding number of glass men. The exceptionally fine program would draw a good representation wherever the meetings were held, but the comparative accessibility of Chicago and the extra-curricular interests of the great mid-Western metropolis will undoubtedly inspire the attendance of many more than usual. It is not always easy for busy glass company engineers and executives to attend distant meetings, but a few days at the Chicago session of the A. C. S. certainly offers many advantages and opportunities at a comparatively small expenditure of time and money.

The Glass Division sessions will be held on Tuesday and Wednesday, April 18th and 19th, in the North Ballroom of the Stevens Hotel. Other division meetings are also scheduled for these two days in other parts of the hotel. Sunday, April 16th, will be the first day of the meeting and will be given over to registration and get-acquainted activities, followed at Seven P. M. by the Orton Memorial Lecture which will be delivered by Lawrence W. Barringer of the General Electric Co. Mr. Barringer will speak in the Grand Ballroom of the hotel and his subject will be a "A Background for Ceramics."

A general session of the Annual Meeting will occupy the attention of the members on Monday, April 17th, and the North Ballroom of the Stevens will be the scene of this activity. The speakers at the general session will discuss a variety of subjects of general interest to ceramists and the program also includes several papers of particular importance to Glass Division members. Thursday and Friday, April 20th and 21st, will be given over to plant trips and round-table discussions.

### The Glass Division Program

The papers prepared for the sessions of the Glass Division this year offer an unusual variety in subject matter and a larger proportion of papers directly applicable to plant problems than at recent meetings. The last remark does not apply, however, to the subjects to be presented on Tuesday forenoon, since these have to do more particularly with the constitution of glass. At the start of the session, the Division will be entertained by Professor Silverman's biographical sketch of Frederick Carder, whose work as an artist and glass-maker have given him an established position as a creative designer and color-maker.

Another report from Doctor Warren's laboratory carries on his X-ray study, which is doing so much toward demonstrating the nature of the atomic arrangements in glasses. This report covers the examination of another simple glass which is of particular interest because of its close relationship to the famous pyrex compositions. With the patient explanations of Doctor Warren, the photographs obtained from these X-ray examinations of tiny glass rods are becoming less mysterious and more informative to most glass men, as the amazing inferences and mathematical deductions are more and more borne out and brought into agreement with previously observed facts.

Lillie's paper on viscosities of soda-silica glasses is a critical study aimed to demonstrate whether or not sodium disilicate, which contains close to 34 per cent $NA_2O$, indicates its presence or existence by a break in the composition-viscosity curve at such a point. Contrary to previous reports by E. Preston, these breaks are not found at 34 per cent and 26 per cent, but smooth curves are drawn from Lillie's data. This may mean something or nothing regarding constitution, depending upon opinions as to smooth continuity of physical-property changes in relation to presence or absence of true compounds. In view of the skill and experience of Dr. Lillie in viscosity work, this paper may be regarded as an authoritative exposition.

A brief address by G. W. Morey may be expected to sum up the best information on constitution of glasses as it is revealed by physical properties or as it affects them. Conservative and accurate statement may be looked for.

Glass blowers have known for hundreds of years that potash glasses have flatter viscosity curves in the working range than soda glasses, but they have not stated

Lawrence W. Barringer

it in just that way. They would say that the potash glasses are "sweeter," or that they are "better natured," but Taylor describes the phenomenon by saying that the potash-silica glasses have the lower temperature-coefficients of viscosity.

Measurements on the surface tension of glasses with various contents of lime and magnesia, such as those to be given by C. L. Babcock of Owens-Illinois, evidently serve to bring into agreement two different methods for measuring this property; to show how it changes with the temperature, and to show that it varies smoothly with changes in oxide composition of glasses.

An unusual subject is handled by Thurnauer and Badger, who have studied the manner in which the dielectric properties of glasses change as temperature rises. This paper should be of particular interest to anyone engaged in the manufacture or use of insulators.

The opening paper of Tuesday afternoon's session is one which has been awaited for some time, because it brings high-speed photography to bear on the problem of propagation of cracks through glass. Most people are quite prepared to believe that these cracks run at nearly a mile a second, and this speed is beautifully demonstrated by taking photographs of a break, using two sparks not quite simultaneous. Like ripples made by a pebble dropped in a pool, the radiating cracks run out in all directions equally, making a perfect circular picture. Edgerton and Barstow of M.I.T. are indeed welcome newcomers to the program.

Peters and Knoop of the Bureau of Standards have had the scientific courage to make another approach to the problem of hardness, this time by making indentations, not scratches, with a ground diamond tool under variable loads on surfaces of glasses and other materials. The achievement of unshattered indentations must be regarded as a good deal of an accomplishment. Such work is apt to bring the study of hardness of glass into some sort of relationship with the investigation of hardness of metal by the Brinnell and similar processes. Their results seem to place glass broadly in the range of steel in resistance to indentation, showing a variation of about two and one-half times for various glass compositions and demonstrating that some glasses are "harder" than fused silica.

A contribution to the application of the phase-equilibrium diagram for soda-lime glasses when alumina is interjected into the picture is made by Silverman of Owens-Illinois in his devitrification studies. The value of alumina in preventing devitrification is well demonstrated in practice, but it is a splendid advance to have this matter placed on a more quantitative foundation.

The next two papers deal with the chemical analysis of glass from two approaches. Webster and Lyle save time on a routine analysis by using a number of samples from which the different oxides may be separately and quickly determined. Vilensky of Owens-Corning, on the other hand, prefers to use a single sample, determining the oxides one after another; and his improvement consists in using perchloric acid instead of hydrochloric in the dehydration of silica. There should be some prospect for interesting debate on the respective merits of these two methods of dissection.

It is again fortunate for the Glass Division that the Geophysical Laboratory continues to exercise its curiosity as to how the rocks got so far so good in a few billion years. Morey reports on experiments in which water is made to dissolve in molten silicates and exert its mineralizing action, enabling the silicates to crystallize at lower temperatures than normally.

What seems to be a very neat scientific job is reported by Finn and his associates, who show why the glass electrode used in pH determinations sometimes behaves erratically. It must of course be attacked somewhat by the water solution and the rate of this attack, which is described as a swelling, changes with the alkalinity or acidity of the solution. Not all glasses show this swelling and this contribution should point the way to the production of better electrodes for such work.

The involved problem of developing an acceptable procedure for durability by the powder method has been tackled again, this time by Tooley and Parmelee. It will be interesting to learn of their methods of finding out how much surface is represented by granular material of given screen specifications; also how they proceeded to determine what has been dissolved from the glass; and how much penetration and decomposition this material represents. Meanwhile, Bacon and Birch of Owens-Illinois have been finding that there is a great deal of discrepancy between rapid decomposition of powdered glass by water and the behavior of glass bottles under service conditions. The trouble seems to be with the temperature of the water in laboratory tests, which accelerates the attack on the glass so as to bring it altogether out of line with the every-day experience of the bottles. We hope that these investigators hold out some prospect of correlation between short time experiment and long time reality, or else that they have other rapid methods to propose which may come into agreement with the tests of time. Finally, Doctor Lundell reports for the Committee on Chemical Durability, and there should be a lively hour on this important subject.

As soon as someone finds a source for cheap vanadium compounds, Badger, Pincus and Weyl are ready with particulars concerning its behavior as a colorant in glasses. However, it may have interesting characteristics for eye-protection or beach-costume-ornamentation spectacles, and for this use cost is of minor consideration. Independently, Greene of Rutgers has also been working with vanadium, and another opportunity is offered for checking results of independent investigators.

Glass technologists are frequently asked why old bottles that have lain in the sunlight for years have developed a beautiful violet coloration. Doctor Weyl now proceeds to bring to bear on this behavior of manganese his practical and theoretical knowledge, and will explain this and other similar phenomena. Perhaps he can show some examples of genuine sun tan acquired by glasses of the out-door or athletic type.

It is entirely fitting and proper that the manufacturers of vitrifiable colors should study the conditions of firing under which these should be applied. Furthermore, these investigators, Robertson and Koch of the R. & H. Division of DuPont, now making their discoveries available to users of these colors in the lettering and decorating of bottles. It seems certain that better techniques can thus be specified for the benefit of all concerned.

(*Continued on page* 147)

# BETWEEN A. C. S. MEETING SESSIONS AT CHICAGO

EVERY visitor to the 41st Annual Meeting of the American Ceramic Society in Chicago, April 16-21, will find plenty of interest and entertainment during the intervals between the technical sessions. Not only has the local entertainment committee provided a program that will suit all desires of John Q. Ceramist to foregather with his kind in more-or-less informal surroundings, but the great city of Chicago itself offers a profusion of opportunities for first-hand acquaintance with world-famous developments in architecture, industry, art and education.

In their own bailiwick in the Stevens Hotel, A. C. S. members will find that the local brethren have fairly outdone themselves to provide adequately for the diversion and enjoyment of their visitors. Ten years have elapsed since the Chicago ceramists have been hosts to their colleagues and every effort has been made to duplicate the warm welcome and cheerful hospitality that made the meeting of a decade ago such an outstanding success. From the well-planned social events at the headquarters hotel to the careful and complete arrangements for sight-seeing, every member will feel that nothing has been neglected to make his visit enjoyable and interesting.

Much of the time on Sunday will be taken up in getting settled and renewing acquaintances, of course, and the new arrivals will be entertained with music presented by an orchestra and a singing-playing musical combination. The Orton lecture by Mr. Barringer will climax the Sunday activities. After the general sessions of Monday, the plans for the evening entertainment include a Bavarian type of open house, at which beer and sandwiches will be served and music will be supplied by a German band. Singers and other entertainers will also be included in this program.

Tuesday evening has been set aside for the usual dinner dance. Dinner will be served from 7 to 9 P.M. followed by dancing until 1 A. M., the charge for this event being $2.50 per plate, tax included. During dinner a special orchestra, with singing and strolling players, will furnish music and a good ten-piece orchestra will later purvey the necessary incentive for the dancing.

Another feature of the social arrangements includes a series of student-alumni dinners which will be held Monday evening at locations chosen by the various college representatives. These dinners will be followed by the Students Reception in the Boulevard Room of Hotel Stevens. Wednesday will be open but arrangements have been made for a tour through the color press department of the Chicago Tribune, followed by attendance at a broadcast from the studios of WGN. Reservations for the broadcast will be limited to 250 persons.

A special treat for women attending the meeting will be a tour of the world-famous department store of Marshall Field & Co., the tour beginning at about ten Wednesday morning. A bridge luncheon at the store, a talk and demonstration on table settings, and probably a style show are also on the schedule. Part of the expense of this tour will be borne by the entertainment committee, so the payment required from the ladies attending will be small.

Regular meeting visitors will immediately sense the wide contrast between the scenes of the 1938 and 1939 annual meetings. It would be hard to imagine a place more different from old-worldly New Orleans than big, bustling, modern Chicago. It represents all that is thought of as typically American in city development; it has gathered from all over the world its treasures of art and history; its institutions of learning hold a foremost place; its industries serve the whole world; and it justifies in many ways its claim to the title of metropolis of the Western world.

At the Stevens Hotel on Michigan Boulevard, A. C. S. members are within the proverbial stone's throw of a number of places that warrant attention. First is Michigan Boulevard itself, often called the most imposing thoroughfare in America, where Grant Park on the east and the towering skyscrapers to the west afford a setting that is memorable. Next in interest and importance is the world-famed Field Museum of Natural History, out toward the lake, an eleven-acre building housing thousands of anthropological exhibits portraying the natural and cultural history of the world. A short distance north from the hotel along the Boulevard is the Art Institute, housing an excellent collection of the best work of ancient and modern masters of painting, sculpture, architecture, design and other fine arts.

The Adler Planetarium, over beyond the Field museum on the lake shore, is something that no visitor should miss. Here one can watch a pageant of the heavens move majestically across the great dome, while lecturers explain the movement of the heavenly bodies. Nearby in Grant Park, south of Roosevelt Road, is Soldier Field, a tremendous amphitheatre which is the largest open-air stadium in the world with a permanent seating capacity of 106,000 and maximum capacity of 145,000.

The A. C. S. visitor will also be fully repaid for a trip toward the southern part of the city, where a place

(*Continued on page* 142)

**The Stevens Hotel, Chicago, where the sessions will be held.**

# FREDERICK CARDER: ARTIST IN GLASS

By
**FRANK E. BARDROF**

**Frederick Carder in his studio at Corning, standing beside the first successful attempt to cast architectural ornaments in glass. The Indian head was made from green glass and the cracks were caused by insufficient annealing.**

At the Stevens & Williams Brierley Hill Glass Works, in Staffordshire, an air of unwonted quiet hung about the place, one afternoon in 1882. The little steam engine that supplied power to the plant machinery had balked and, in the yard at the side of the building, the bearded, sweating, harassed caretaker paused from time to time in his remedial efforts to listen to the comments and suggestions of a small group of men nearby. Most of the group were members of the official family of the company and, though their suggestions were exceedingly amateurish, the tormented engineer held his tongue in the presence of his superiors. Back and forth he hurried, from the engine in its shed to the boiler out in the open yard and back again. But all to no avail.

At this inauspicious moment a young chap of about 18 years stepped out of the group and offered his suggestion for curing the trouble. The worried man paused in his efforts, looked the youngster over from head to toe and realized that this was no boss of his. Drawing himself up, he released all of his pent-up scorn in a withering query. Why did this callow youth stick in his oar when he didn't know any more about a steam engine than a puling infant, or words to that effect. A red tide started at the young man's collar and engulfed his ears as he realized with horror that the old man was right; he knew nothing about steam engines and less about running them. Without a word he turned and started back to his little office, but as he went he could fairly feel the amused smiles of the group boring into his embarrassed back. Fred Carder had just gotten one of the toughest jolts of his young life and he still looks back at that moment of shame as one of the turning points in his young career.

But young Carder wasted no time in sulking or self-pity. That evening found him in his father's library deep in the Encylclopedia Brittanica, reading everything he could find about steam engines, boilers, valve mechanisms, and so forth. Within a few days he had secured a little pedal-operated lathe and with this equipment he proceeded to build a complete model steam engine and boiler in his spare time. When it ran, the young fellow was satisfied that he was now conversant with the fundamentals of steam power equipment, but the incident is of greater interest as a foretaste of the characteristics that have brought Frederick Carder to international renown in his chosen field. Blessed with an inquiring turn of mind, he combines with it the self-confidence, patience, determination and energy to accomplish things that others consider impossible, and his achievements in artistic glassware are known and admired the world over.

Now let us jump fifty years from that day in the little Staffordshire glass works. It is now 1932. Frederick Carder is full of years and honors at 68, but with apparently unabated energy he is deep in another pioneering project whose results will amaze and charm every one who sees it, artist and layman alike. During the last twenty years of the intervening half-century he has at times attempted indifferently to cast small art objects in glass and he is now in the midst of a demonstration to show that large architectural pieces can also be produced. Down in a corner of the big glass works at Corning lies a big 800-pound lump of glass cooling slowly in its mould. An internationally famous architect and a committee of foreign representatives will visit the plant in a couple of weeks and by that time the glass will be cool enough for the mould to be opened. Then comes

another jolt in the form of a message saying that the delegation will arrive a week earlier than expected and that the demonstration must be made at that time, as the foreign contingent must sail immediately thereafter.

At the appointed time the visitors arrived and were taken into the plant where workmen were starting to remove the sand covering from the ceramic mould in which the glass was encased. The sand was hot; the mould was hotter; and Carder knew that the glass inside was far from being ready for exposure to the atmosphere. However, there was nothing to do but go ahead, so the smoking mould was broken apart and there, before the interested gaze of the onlookers, appeared the hawk-like features of an Indian head of heroic size, complete with feathered head-dress. But the glass was too hot and, even as the visitors admired the amazing thing, several large cracks spread rapidly through the mass of glass. It was apparent, however, that the trouble was caused by insufficient annealing, so the demonstration was an unqualified success, as far as the really difficult parts of the process were concerned.

Thus began the making of cast-glass pieces for architectural ornament and decoration, the best-known application of which is probably the glass screen above the entrance of the RCA building in Radio City, New York. Intrigued by the possibilities in the art of casting glass, Mr. Carder then turned again to the casting of smaller pieces and his achievements during the past few years make a fitting climax to a long career of creative effort in the art of glass making. He has actually succeeded in adapting the *cerré perdu*, or "lost-wax," process to the making of glass sculpture, an accomplishment that would assure him lasting fame, even if all of his previous attainments were forgotten.

The *cerré perdu* process was known and used by the

**This charming vase is noteworthy not only for the effect produced by partial polishing, but also for its technical excellence and difficulty. It exhibits craftsmanship of the highest order, as well as masterful design.**

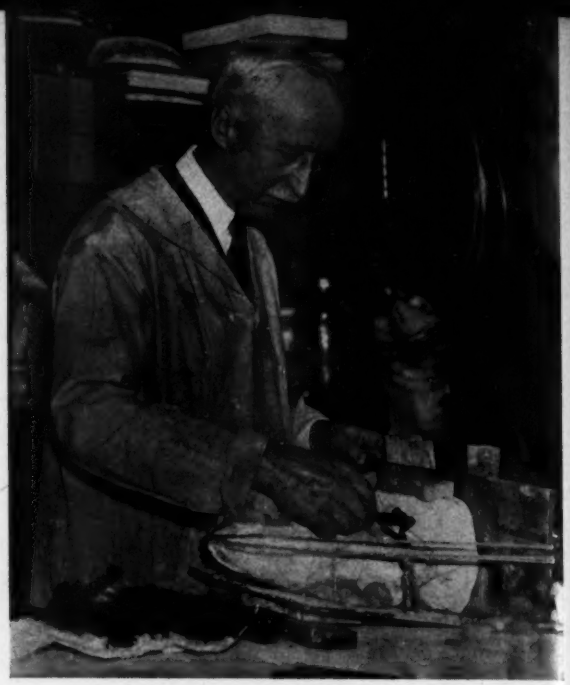
**"WILD DUCKS." This marvelous piece of glass sculpture illustrates the dynamic grace of Mr. Carder's modelling and the translucent liveliness imparted by glass as a medium. The technical difficulties surmounted to form such shapes in glass are apparent.**

Chinese and the Greeks many years before the Christian era, but it was lost for many centuries until reinvented by Benvenuto Cellini and used by him for his exquisite work in bronze, silver and gold. Ever since about 1890, when he exhibited a bronze head cast by the *cerré perdu* process at the Royal Academy of London, Frederick Carder had felt that glass could and should be cast by the same process, but it took many years of study and experimentation before the successful technique was perfected. The bare description of the Carder technique makes it seem quite simple, but it really requires the talent of a top-flight artist coupled with craftsmanship of the highest order.

After the design is conceived and modelled in clay or wax, it is then cast in plaster of paris. If of an intricate nature with projecting portions such as arms and legs, the model is cut in pieces and gelatin moulds of the component pieces are made, thus permitting all undercutting necessary for work in the round. Wax casts are made in the gelatin moulds and the separate wax pieces are then assembled, giving an exact replica in wax of the original model. The wax replica is then touched up by the artist and finally encased or invested with a ceramic composition. When the ceramic mould has become dry and set, the wax is melted out and the mould is carefully brought to a high temperature. Molten glass is then poured into the mould and, after a long period of careful annealing and cooling, the mould is broken away, leaving the glass replica of the original model. Adhering material from the mould may be cleaned off with the sandblast and the piece may be polished, if such treatment is called for in the design.

To the glass maker the manifold difficulties in the Carder technique are immediately apparent, especially those which have to do with the high melting temperature, tendency to chill and necessity for careful removal of cooling strains. Other problems will be recognized by the artist, because glass sculpture must be cast solid of necessity and the design must be made heavy enough near the base to support the weight of glass above. But Frederick Carder has solved all of these problems and surmounted all of these difficulties completely, and a profusion of delightful pieces already bear witness to his artistry. Even the accompanying fine photographs fail to do justice to the airy beauty of this work. Much of their charm comes from the medium itself, which produces a translucent liveliness impossible with any of the metals or other opaque materials. Through Carder's capable hands glass now takes its place in the world of sculpture, as it has in the field of architecture and other more utilitarian pursuits.

The beholder must wonder what manner of man this is, who pioneers an art in an entirely new medium when past man's allotted span of three score years and ten. First of all, he is a creative artist. His designs are not only original; they also show an exceptional flair for line and form, coupled with a true simplicity that is neither cluttered up with rococco decoration nor hampered by the square ugliness of the ultra-modern. Second, he is a craftsman of exceptional skill. Third, he is a dyed-in-the-wool Englishman, an unusually good citizen of the U. S. A. and his home town, a confessedly irascible person who likes to bark and seldom bites, and the proud possessor of a vocabulary that packs more



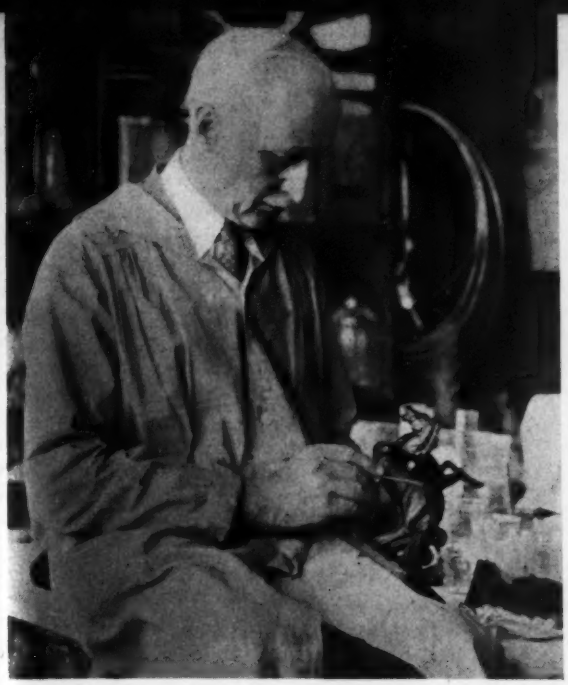
**Ceramic mould for a glass art object receives its finishing touches. The ceramic mould is formed around a wax model, after which the wax is melted out leaving the mould ready for the glass. Parts of a gelatin mould for making the wax model appear on the table at the left.**

fireworks than a Chinese New Year. But let us go back to Staffordshire again and pick up the story from the beginning.

The Leys Pottery, Brierley Hill, Staffordshire, had been in the hands of the Carders for many years and in the 1860's had come under the management of Caleb Carder, an able potter and manager. Caleb's wife was Annie Weidlein (pronounced Waidlin), whose father had been manager of Foster's Iron Works at nearby Stourbridge when they built the famous old "Stourbridge Lion," the first steam engine to run on rails in America. In the Leys Pottery the major product was salt-glaze stoneware, made in the shape of bottles and jars and other receptacles which Caleb Carder sold to the dyeing industry in large quantities.

Frederick, son of Caleb and Annie Weidlein Carder, was born at Brierley Hill in 1864. His home and school life as a boy followed the usual pattern in a well-to-do English family of that time, although he remembers himself as full of wild ideas and a bit on the "cocky" side. At the age of 14, young Frederick had finished grammer school at the head of his class and had passed with credit the difficult entrance examinations to Oxford, but right there he balked, informing Caleb that he would not bother with any further schooling and that he would go to work in the pottery. Neither fatherly advice and argument nor motherly entreaties availed against this strong-willed youngster and he was finally allowed to have his way and start in to learn the pottery business.

But Caleb's name was Carder, too, and if young Fred thought he was going to rise in the pottery business in anything other than the hard way, he was much mistaken. The boy was put to work shoveling coal and wheeling it to the kilns and was kept at it for nine long dirty months, working from six in the morning to six in the evening each day. It took only a couple of months for young Frederick to realize that his unfortunate cockiness had led him astray, but instead of throwing up the job he started to spend two nights a week at the Dudley



**Artist Carder touches up the wax model for one of his charming bits of glass sculpture. This is a part of the *cerré perdu*, or "lost wax," process, never before used with glass.**

Mechanics Institute, studying chemistry, electricity and metallurgy, and three nights a week at the Stourbridge Art School.

Three years later, at the age of 17, young Carder left the pottery and started his long career in the glass world, signing a contract to serve the Stevens & Williams Glass Works as designer. Thus, at an age when most boys are still in high school, he was holding an important job, full of ideas and pretty cocky still, to use his own words. Thus, he felt qualified to offer his counsel in almost any situation and thus came about the embarrassing "jolt" mentioned at the beginning of this story. To this day he feels that such timely jolts have been as effective in shaping his career as the ceaseless study and tireless experimentation. Even the artist has to keep his feet on the ground, according to Frederick Carder.

As a matter of fact, the steam engine episode did not end with the completion of the model mentioned earlier. The young Stevens & Williams designer was interested in the new art of electro plating and thought it might be applied to the making of the more intricate glass moulds, but the Daniell cells which were the only source of current available did not deposit the metal fast enough to suit him. He determined, therefore, to use his new-found knowledge of the steam engine in the construction of a half-horsepower engine and a dynamo which would speed up the electroplating operation. The engine was a success, and so was the dynamo, except that the latter was unknowingly wound for high voltage and low amperage and was therefore, useless for the plating work. One of the accompanying illustrations shows a portrait medallion of "Old Chips," which is a memento of the electroplating activities when Carder was still in his teens. "Old Chips," by the way, was the engineer who caused those embarrassing moments when the power plant broke down.

The night-school schedule was continued after he joined the glass company, a matter of some ten years in all, and just to take up his spare time, he was continually designing and modelling for other glass and terra cotta manufacturers. During the ensuing years many pieces of his work were exhibited and brought the young artist many awards, gold, silver and bronze, as well as an Art Master's Certificate given for exceptional qualifications. He started an art class in the factory which later came under the auspices of the Science and Arts Department of London, from which young Carder received a gold medal for modelled design. The same year he took a vacation course at the Royal College of Arts in Kensington, at the end of which his work was selected as the best among the thirty students and he was offered a three-year traveling scholarship. On account of the contract with the glass works in Brierley Hill, however, he was unable to use the scholarship. Those were the days in which contracts were considered binding under any and all circumstances.

His extraordinary talent and activity was soon recognized in Staffordshire and he was asked, about 1888, by Thomas Turner, Director of Education for the County Council, to start a class in glass-making. Meanwhile the rising young artist and glass-maker had married Miss Anne Walker the preceding year and had settled thoroughly into his chosen profession. The course in glass-making was started and was a success from the beginning, the curriculum consisting largely of lectures and demonstrations with two Fletcher furnaces. This course, by the way, was the forerunner of the present Society of Glass Technology. A number of Carder's students became well-known in the ceramic world and among them was George Service, who later became a vice-president of Wedgewood & Co., New York.

The following decade passed busily as Frederick Carder studied, taught and perfected his ceramic art technique. During this period his three children, Gladys, Cyril and Stanley, were born, and near the turn of the century he was made a fellow of the Royal Society of Arts. He performed more and more duties for the County Council and finally, in 1902, was sent by the director to investigate and report on the glass trade in Austria and Germany. The report, when printed and distributed, caused a veritable furore in England and then the event that changed Frederick Carder's whole life occurred. He was commissioned to visit the United States and make a similar report on the American glass business. He came; he investigated; he made his report; and he went back to England with his mind made up on one very important point. Henceforth, Frederick Carder would make the United States of America the scene of his activities, and time has proved that the notion was a good one for all concerned.

Within a few months he was back in America with letters of introduction and with the final admonition of his good friend Capt. William Webb, M. P., in mind: "If you go to the United States stay in New York State; the rest of them are no good." He went first to Washington, however, and from there to Pittsburgh where he presented a letter of introduction to Andrew Mellon and was introduced by him to some of the glass firms in that vicinity. Then he did make his way into New York state and visited the famous Hawkes glass-cutting works in Corning. He was already acquainted with T. C. Hawkes, Sr., through business dealings while he was still in England, and this visit led finally to a decision to stay in Corning and to the formation of the Steuben Glass

Works, with Mr. Hawkes as the main stockholder and Frederick Carder, Willard Reed and Mrs. Reed, as incorporators. Thus came into being the little glass company whose name, taken from the county in which it was located, has become famed the world over as a hallmark of really fine glassware.

A site for the new plant was secured on Erie Avenue and construction was started immediately, the construction period also being notable because it included the birthday of the thunder-and-lighting section of the Carder vocabulary. Many have wondered whether this choice collection of sizzling expletives and deep purple epithets was the result of a long period of gradual growth or rather something that lighted up the world all of a sudden, like a meteor or something. But the owner himself, with no more than the usual twinkle in his eye, states that this talent sprang into being in all its completeness during a few short moments while the Steuben plant was being built.

His family was still in England and he occupied a room in a house down on First street in Corning, meanwhile. About two o'clock one morning he was aroused by the landlady and informed that a messenger had just brought word that the partly finished Steuben plant was burning up. Much upset by the news of this early disaster, he dressed hurriedly and started up First street at his best English gallop. In those days the Corning sidewalks were of the wooden variety and, as the worried business man rounded the corner where the post-office now stands and tore up Erie Avenue toward the scene of the fire, his foot struck a loose board which in turn flew up and struck him on the side of the head. In those few rosy moments as he flew through the air with the greatest of ease and landed in the dirt and cinders of the nearby Erie right-of-way, the individual Carder style of eloquence sprang into being, full-bloom, full-panoplied, and with all the pristine vigor that has characterized it ever since. In less time than it takes to tell, practically every pertinent subject had been covered in detail, from Corning sidewalks, damyankees and midnight fires to the whole United States of America in general. Soon, however, the storm passed; the efforts of the volunteer firemen were successful; the new Steuben plant was completed. But the fetching method of oral communication, born that wild night near the Erie tracks, still remains.

In 1903 cut glass was to the fore, so the first activities at Steuben were directed to the making of blanks for cutting, but within a year or two Mr. Carder's fondness for color had led him again into the manufacture of colored glass. As time went on he resurrected or reinvented methods of glass coloring and decoration that had remained unknown since early times; he bought out new and individual ideas for both color and decoration; and he perfected many new and unique variations in the technique of melting and fabrication of artistic glassware. His activities and achievements in the decade preceding the World War brought lasting fame to Frederick Carder and his Steuben Glass Works. A great variety of artistic glassware, such as had never been made before, was produced, including the splendid Aurene, the silky Verre de Soie, Calcite for illuminating ware, fine engraved rock crystal effects, etched-in colored glasses, and sculptured glass formed with the aid of acid and sandblast. During this period fine colored glassware swung into popularity with the buying public also, this trend resulting in a very nice volume of business for Steuben and taxing its production facilities to the utmost.

Many of the pieces of Steuben glassware made by Frederick Carder and his staff of craftsmen have found their way into museums or private collections where they are cherished as the highest attainment in the design and manufacture of artistic glass.

The Steuben Glass Works ceased to operate as an independent unit in 1918. During the war the manufacture of artistic glassware was not considered an essential industry and Steuben's supplies were cut off, the lack of fuel finally necessitating a complete shutdown although the gas producers were operated on a mixture of fine slack and sawdust for several weeks. In this situation the Steuben Glass Works became the Steuben Division of Corning Glass Works and its facilities were given over to the manufacture of lamp bulbs for the duration of the war. Frederick Carder became Art Director for Corning, designing and supervising the manufacture of the Steuben ware, as before, and reaching out to conquer new fields in the making of artistic glass, as has already been told.

Not only did the war bring a radical change in the business relationships of the artist; it also reached its long tentacles into his family and took his only surviving son, Cyril, the younger son, Stanley, having died at the age of seven before the Carders left England. Cyril Carder was educated at Peekskill Military Academy and Ohio State University. He enlisted immediately after the United States declared war and was trained at Madison Barracks, becoming lieutenant in Company D of the 16th Infantry, A.E.F. He was killed near Soissons in July, 1918. Frederick Carder had the solemn honor of receiving the posthumous presentation of the D.S.C., awarded to his son for bravery in action, but the shadows brought by this overwhelming loss still lie deep in the father's eyes after a lapse of twenty years.

Frederick Carder holds memberships in many technical and art societies and has been the recipient of many honors from his contemporaries. As already mentioned, he has been a fellow of the Royal Society of Arts for over 40 years; he is also a fellow of the American Ceramic Society, to whose programs he has made many important contributions and from which he received, in 1935, the Fergus Binns medal for outstanding achievement in Art in Industry; and his third fellowship is held in the Society of Glass Technology, with which he has maintained an active connection for many years.

**This 4-inch portrait medallion is a memento of Frederick Carder's early experiments with electroplating while still in his teens. The great talent that has given the world some of its finest glassware is already in evidence. The young artist's troubles with the letter S are overshadowed by the excellence of the portrait and his mastery of a then new process.**

Other society memberships include the American Chemical Society, for some 28 years; the Association of Arts and Sciences, Washington, D. C.; and the Society of Illuminating Engineers. In 1927 he received the Friedsam Gold Medal from the Architectural League of New York, the award being bestowed on Mr. Carder as the one who had accomplished most for art in industry during the year. For several years he was honored by the Metropolitan Museum of Art with a membership on its advisory committee for industrial art, an assignment to which he has given much time and expert cooperative effort.

In Corning, Frederick Carder has always taken a busy and important part in the life of the community, exhibiting an unusual ability to instigate worth-while projects and carry them through to a successful conclusion. Corningites are not in the least upset by the well-simulated but usually innocuous Carder truculence; they appreciate greatly each new flight of peculiarly Carderesque eloquence; they esteem his active and effective efforts in behalf of many community projects; they take a vicarious but very real pleasure in each new honor that comes to their fellow-citizen; and they are just a little surprised that such an unassuming, active, neighborly and friendly person is actually a renowned artist whose fame is world-wide.

Shortly after the war Fred, to you Rotarians, organized Corning's Rotary Club, became its first president. and has continually taken an active part in its work. He was a charter member and organizer of the Corning Country Club and still shoots a pretty good game. The fine Corning school system is another testimonial to his years of unselfish and cooperative effort as member and president of the Board of Education. He was also active in the transformation of the old club property at the corner of First and Pine into the Corning Public Library and the library building houses a fine collection of Steuben-made glassware in a profusion of sizes, shapes and colors, presented by the artist himself. An outstanding feature of the library building is a memorial window on the second floor, designed, executed and presented by Mr. Carder. The main center panel of this window is noteworthy not only for beauty of design and color, but also because the figure and the names of Corning's World-war dead are cast in relief on amber glass. The rare beauty of this panel cannot be equalled by any other method of decoration, but it took a rare combination of artist and craftsmen in glass to produce it.

The confines of a magazine article are all too restricted for any competent and complete review of the accomplishments and activities of this talented man. His career is remarkable not only because of his great sensitivity and individuality in truly artistic forms and colors, but also because these gifts have been combined with the finest sort of skilled craftsmanship in his chosen medium, secured only by continuous study and ceaseless practice. With such talent and such skill he has not hesitated to attempt the seemingly impossible and the art world has at times been startled at the boldness of his conceptions, as well as by their sheer beauty of form and color. In the glass world his place is secure and future generations will look back with veneration and appreciation to—Frederick Carder: Artist in Glass.

**"CHILD OF THE SEA". Frederick Carder's great artistic talent and his complete control of the *cerre perdu* process in glass is shown by this lovely little figure. Never before has such exquisite work been achieved in glass.**

**BETWEEN A.C.S. MEETINGS**
(*Continued from page* 135)

of outstanding interest is the Museum of Science and Industry in Jackson Park. This is the reconstructed Fine Arts Building of the World's Fair of 1893 and now houses this museum dedicated to industry and the sciences. Moving models and actual machinery and instruments, many of which the visitor may operate himself, demonstrate scientific principles and their applications to industrial processes.

Westward from the museum along the Midway is the University of Chicago, one of the better-known universities of the world. Many of the buildings are patterned after the Gothic style of the English universities, the most interesting and impressive buildings being those around Hutchinson Court, including Ida Noyes Hall, Harper Library, Oriental Museum, Billings Hospital, International House and the new chapel.

Still farther west, bounded by Halstead Street, Pershing Road, Ashland Avenue and 47th Street, are the Union Stock Yards. These have attracted thousands of Chicago visitors yearly and tours of a number of the great packing houses can be made.

Other impressive sights around Chicago can only be mentioned here. Important buildings from an architectural standpoint include the Palmolive Building, Tribune Tower, Field's Civic Opera and Daily News buildings. The Board of Trade building at LaSalle and Jackson Boulevard merits a visit also and trading activities can be viewed from a special visitor's gallery; Lincoln Park holds much of startling interest; the Merchandise Mart is the world's largest building with 4,000,000 square feet of floor space; and the great Navy Pier extends almost a mile into Lake Michigan. The main campus of Northwestern University is in Evanston, some 12 miles north of the Loop, where the colleges of liberal arts and sciences are located. The other center of the university is situated at Lake Shore Drive and Chicago Avenue, where visitors can find the schools of medicine, dentistry, law, commerce and journalism.

The A. C. S. visitor will have an opportunity also to visit almost any kind, type and size of industry while in Chicago. The local committee has arranged several plant trips for the various divisions on Thursday and will be glad to cooperate with any member who desires to visit industries that are not already scheduled. Detailed information regarding the various industrial tours will be available at the meeting.

## CERAMISTS TO EXHIBIT PHOTOGRAPHY

In connection with the Forty-first Annual Meeting of the Society, members interested in pictorial or technical photography are invited to exhibit prints under the auspices of the Ceramic Camera Club which as yet is unorganized. A number of individuals have cooperated in a preliminary organization. A get-together meeting will be held during the Society Meeting week in Chicago, at which time a permanent set-up will be provided for the Camera Club.

Prints may be of any character, either purely pictorial or technical. Entries are limited to members of the Society. Until permanent rules are established for future exhibits, work may be entered by those who have had enlargements made by commercial shops, but the negative must be the work of the exhibitor.

Prints must be mounted on 16 x 20 in. vertical mounts. Each entrant may submit four prints. No entry fee is required. The cost of this exhibition, as well as the expense of this notice and similar items, will be covered by subscription, including postage in returning prints where such prints are not taken home by members in attendance. Every effort will be made by the committee in charge to take good care of the prints.

Mail your prints directly to the following address:

American Ceramic Society,
Camera Club Exhibit,
Room 421-A,
Hotel Stevens, Chicago, Ill.

Prints must arrive not later than Saturday, April 14. When you mail prints send at the same time a memorandum giving name and address of entrant, number of prints forwarded and, if possible, the titles of same, this memorandum to be mailed to:

J. M. McKinley,
1012 National City Bank Building,
Cleveland, Ohio.

All such memoranda should reach Cleveland on or before April 13.

Be sure to mark on the back of each mount the name of maker and title of print. Subject title of the print may appear on the front of the mount in the customary manner at the lower left corner of the print. The maker's name may be placed below the lower right corner.

A number of individuals have indicated their desire to participate in this show. To assist the committee in taking care of final arrangements it is urged that those who expect to participate serve notice of the fact as quickly as possible. The space provided will accommodate about 80 prints. It is apparent that not more than 20 individuals will participate, but in event that a greater number of entries turn up it may be necessary to hang three prints, for example, from each entrant instead of four, or to find additional convenient space. If the present committee has early knowledge of the requirements, all prints entered can be hung.

The temporary committee of the Ceramic Camera Club is composed of J. M. McKinley and J. Earl Frazier.

## KNOX PLANT IN CANADA

According to Roy R. Underwood, president, Knox Glass Associates, Inc., Oil City, Pa., the Knox group has caused to be formed and incorporated under the laws of the Dominion of Canada a corporation to be known as Canadian Knox Glass, Ltd., with plant and general office in Oshawa, Ontario. Buildings suitable for the purpose have been purchased, a furnace will be constructed therein, and the buildings will be equipped with modern machinery for the manufacture of glass containers. It is contemplated that the building will be in operation about July 1st.

## O-I TO STIMULATE BUILDING ACTIVITY

General stimulation of building activity is expected to result from a nation-wide architectural competition being sponsored by the Owens-Illinois Glass Co. Through a series of four Insulux Glass Block Competitions open to architects and designers, Owens-Illinois is offering a total of $15,000 in competition. The competitions will run consecutively and will embrace houses, store units, dairies and newspaper buildings.

# AN ATTEMPT TO CORRELATE SOME TENSILE STRENGTH MEASUREMENTS ON GLASS: IV

**By JAMES BAILEY**
**Hartford Empire Co.**

*This concludes Mr. Bailey's discussion which began in* THE GLASS INDUSTRY *for January.—The Editor.*

### The Importance of the Starting Point of a Test

If one examines the sum in Table XII corresponding to any particular stress, it can be seen that very little change in measured strength would result from starting the test at 90 per cent of the breaking strength. Thus the sum at 9,000 is .2424. The breaking strength at a sum of 1.2424 is slightly less than 10,800 lbs. The breaking strength starting from zero is (Sum = 1) slightly more than 10,500 so that a difference of less than 300 lbs. per sq. in. would be found if the test had been started at a stress of 9,000 lbs. instead of at zero. While this would be true if all the samples broke at the average stress, it introduces a very grave error when the samples have the usual spread of breaking strength. The explanation is rather complicated.

If the specimen breaks during the test it must be assumed that it broke because the stresses were magnified by the flaws until the breaking strength had been reached. It has already been shown that the flaws change the strength level and that comparable results are obtained only when the rate of stressing is increased in the proportion that the strength is increased. In the case of a steady load the effect is simply to change the units of the stress ordinate in Fig. 13 as has been done on the right-hand end.

Suppose that we elect to test Preston's 2" x 16" x ¼" slabs in steps of 1,000 lbs. per sq. in. stress starting at 7,000 lbs. stress and the loading interval is 10 seconds. The stress time effect would be:

10 sec. at 7,000 = .02631
10 sec. at 8,000 = .09333
10 sec. at 9,000 = .2455
10 sec. at 10,000 = .5624
X at 11,000 = X (1.149)

These would be additive and the glass would break after about 2 seconds at 11,000 lbs. stress. Suppose that the flaws in the next piece were greater so that:

$\frac{F_o}{F_1} = .75$ Then the effect would be

| *Time* | *Computed S* | *Corresponding Flaw Stress* | *Breaking Effect* |
|---|---|---|---|
| 10 sec. | 7,000 | 9,333 | .3341 |
| 10 sec. | 8,000 | 10,666 | .8918 |

The piece would break after 7½ sec. at 8,000.

Let $\frac{F_o}{F_1} = .5$

| *Time* | *Computed S* | *Corresponding Flaw Stress* | *Breaking Effect* |
|---|---|---|---|
| 10 sec. | 7,000 | 14,000 | X (.6457) |

The piece would break after about 1.3 sec.

If we had started at 6,000 the breaking effect would be .2138 per second so that the piece would break in about 5 seconds. If it had been started at 5,000 the piece would have stood the full 10 second interval. In other words, the point at which the initial load may be started with safety depends upon the weakest test piece in the series. Usually an initial load which causes a stress of about half the average breaking strength is permissible. If more than this is used there is a probability that the values will be increased by a sizeable fraction of one stress step.

### Increasing Stress Increments

As has already been pointed out, the stress at the apex of the flaws controls the break. The effect is to magnify the stress steps (at the flaw apexes) in the exact ratio of the stress concentration factors. Hence, it would be more logical to use a series of steps arranged in geometrical proportion than to use equal steps. In testing bottles, for example, a series of applied pressures built up by multiplying some unit pressure such as 100 lbs. per sq. in. by a factor of, say, 1.2 giving a series of test pressures of 100, 120, 144, 173, 208, 250, 300, 360, etc., would be preferable from a scientific aspect to a series of 100, 150, 200, 250, 300, 350, etc. The former gives equal importance to both the weak and the strong bottles, whereas the latter tends to raise the apparent strength of the weak ones and diminish the strength of the strong ones.

These same remarks apply to a continuously increasing stress such as used by Black.

At the present state of our knowledge it is doubtful if the added mechanical difficulties due to a geometrical series can be justified.

### Comparison of Preston's Two Curves

The curve of Preston's Fourcault Glass is not so steep as is the one for his plate glass. The difference is great enough so that it cannot be accounted for by the size of the specimens or by a change in the stress concentration factors of the flaws. It appears, therefore, that there is a distinct difference (possibly surface compression in the Fourcault pieces) in the two glasses of some more fundamental nature, but the curves tend to be parallel at the upper end and the slopes of both agree with Black's curve much more closely than do similar curves by some other observers. Borchard[24] gives the following equation:

$F = F_B (a - b \log h)$ where
$F_B$ = rapid breaking strength
h = time in minutes between applied load and breakage
a = a constant = .77
b = a constant = .094

He states that this gives good agreement from 10 seconds

[24] K. H. Borchard. Glastech. Ber. 13, 52-7 (1935).

to 1 hour, after which the values are nearly constant. This curve is nearly a straight line when plotted on Fig. 13. Moreover $F_B$ can have no significance if Preston's and Black's work is valid, since the rapid breaking strength depends only upon the time interval.

If $F_B$ is a constant, then Borchard's equation will have the form

$F = A - B \log h$, where A and B are constants for any series of tests.

An equation of this type cannot represent more than a very small range of either of Preston's curves. It requires an equation of the form of

$(S - B)(\log [T + A]) = K$ to fit Preston's data where S is the strength, T is the time and A, B and K are constants.

The equation $(S - 3{,}000)(\log [T + 9]) = 10{,}100$. (S in lbs./sq. in. — T in seconds) gives values of 11,830, 8,500, 6,110, 5,430 for Preston's lower curve corresponding to Table X, and the equation $(S - 5.800)(\log [T+4]) = 7{,}000$ gives values of 13,130, 9,680 and 7,950 corresponding to those in Table XI.

### Recovery of Strength

Some authors believe that, if the strength is found to diminish with time under sustained stress, the strength should gradually be regained when the stress is released. No data can be found bearing definitely upon this point. However, simply removing the stress would not, if the glass were annealed, provide any force to close up an incipient flaw. Moreover, alternating stresses should not result in fatigue failure if this were true.

One series of tests conducted by the author wherein strips of window glass were loaded by bending to a stress corresponding to approximately 12,000 lbs./sq. in. in about .2 of a second, then released and reloaded at a rate of one cycle per second, showed that the samples were eventually broken by this repeated loading. The usual spread in results was found but the evidence was definite that the effect of repeated loading was, at least to some degree, accumulative. Fatigue effects could, no doubt, be entirely removed by annealing or heating the glass to a sufficient temperature to permit molecular rearrangement.

## Chapter IV: CORRELATION OF RESULTS

Thus far the following *factors* have been discussed:

1. The "Area Function" which is a measure of the probability that a bad flaw will (a) occur in the region of high stress, and (b) that it will be orientated into its most weakening position with respect to the direction of stress.

2. The weakening effect of the flaws, which is probably a combination of the size of the flaws and their orientation, due to the particular method of manufacture.

3. The relation of the strength with respect to the rate of stressing.

If these *factors* have been properly isolated, and if they are typical for all lime glass specimens, it should be possible to show that the measured strength of Run G rods is the same as that of the other specimens, when the basic corrections have been applied.

An exact agreement can hardly be expected when the wide divergence in size and type of specimens is considered. In particular, the degree of surface compression, which will increase or decrease the strength in the amount that it is greater or smaller than that existing in the "Run G" cane, has been entirely neglected. Nevertheless, the results can be so closely correlated that a detailed exposition of the method is justified.

If S = the strength of glass under specified conditions.

A = the area function strength of Run G rods corresponding to the new type of test piece.

$(F_o/F)$ = the relative stress concentration of the flaws.

(R) = the relation of strength to rate of stressing according to Black, then the strength of any specimen of lime glass can be expressed by an equation of the type, $S = f(A) \times f(F_o/F) \times f(R)$

The functions A and R are given in graph form. The function $F_o/F_1$ must be arrived at by experience. Several sets of data have been examined, including those of this paper and the factors controlling $F_o/F_1$ appear to be about as follows:

1. For test pieces having an all over fire polished surface and having received commercial treatment as regards handling and shipping $\frac{F_o}{F_1} = 1.0$.

2. Test pieces having an all over fire polished surface but very careful handling $\frac{F_o}{F_1} = 1.1$ to 1.4.

3. Carefully ground and polished test pieces, depending upon the freedom from scratches. (Fine ground glass is often stronger than the same glass after polishing.) $\frac{F_o}{F_1} = .9$ to 1.2. Less carefully ground specimens, .4 to .9.

4. Fourcault sheet glass or first quality plate glass cut into test pieces with a diamond, the diamond marks being on the compression side $\frac{F_o}{F_1} = .9$ to 1.0.

5. Same with one diamond mark on tension side $\frac{F_o}{F_1} = .75$.

6. Same with both diamond marks on tension side $\frac{F_o}{F_1} = .5$

*Note:* Items 4, 5 and 6 will generally be reduced if the specimens are cut with a steel wheel cutter. Item 6 may drop to .35 if the cutter is in bad condition and splinters are caused by using excessive pressure.

7. Thin blown glass tested by internal pressure (J. M. McCormick's electric light bulbs) $\frac{F_o}{F_1} = .78$.

8. Bottles tested by internal pressure, commercial quality $\frac{F_o}{F_1} = .5$ to .7.

9. Acid polishing, which reduces the destructive effect of the flaws, will increase the strength of any of the above by a factor of from 1.3 to 1.5.

10. The process of drawing fine fibers results in an enormous increase of strength which can be accounted for only by an added factor.

**The Correlation Process**

The simplest method of correlating the data is shown in Fig. 15.

The first step is to find the Run G strength of a test piece having the shape of the specimen to be investigated. The data of Holland and Turner[25] will be discussed in detail for purposes of illustration.

TABLE XIV. RUN G STRENGTH OF MECHANICALLY GROUND AND POLISHED THEN FIRE POLISHED (Holland & Turner)

| Item | Width Cm. | Width In. | Mod. Rupt. $Kg/cm^{-2}$ | Mod. Rupt. $Lb./in^{-2}$ | Stressing Rate $Lb./in\ (m.)^{-2}$ | Stressed Area (1) | N (2) | Run G Strength (3) |
|---|---|---|---|---|---|---|---|---|
| 1 | .40 | .1575 | 1299 | 18,480 | 46,800 | .01916 | .133 | 14,500 |
| 2 | .485 | .192 | 1224 | 17,400 | 38,400 | .0233 | .162 | 14,100 |
| 3 | .73 | .287 | 1114 | 15,860 | 24,700 | .0347 | .242 | 13,500 |
| 4 | .775 | .305 | 1030 | 14,650 | 24,200 | .0368 | .257 | 13,400 |
| 5 | .945 | .372 | 991 | 14,080 | 19,800 | .0449 | .313 | 13,100 |
| 6 | 1.19 | .486 | 935 | 13,290 | 15,700 | .0565 | .392 | 12,700 |

1. The area overlying tensile stresses 96 per cent or greater of the maximum, in sq. in.
2. Above area divided by .1438.
3. Lbs. per sq. inch Fig. 4.

These specimens were tested in bending by one central load. The supports were 7.6 cm. apart (3″) and the thickness varied from .26 to .295 cm. (.11″ approx.). Since the surfaces were fire polished all over, the factor $F_o/F_1 = 1$.

Referring to Fig. 15, the ordinate scale is four times that of the abscissa. The lines of equal stress concentration slant upward at such an angle that their tangent is ¼ instead of 1 as in Fig. 11. Black's curve (B) has been drawn in. The Run G strengths of Table XIV have been located on the vertical line corresponding to a rate of stressing of 3,200 lbs. per square inch per minute. These are labeled 1 to 6 corresponding to the item number in the table. A series of equal flaw apex stress lines 1A, etc., are drawn from these points to Black's curve. The Curve 1B may now be constructed so that all points in it are equi-distant from Black's curve when measured along lines parallel to 1A. The vertical lines 7, 8, 9, 10 and 11 are next drawn corresponding to the rates of stressing of Items 1 to 6 in the table. The vertical line 7 cuts the curve 1B at B. This is a point giving the Run G strength of a test piece of the same shape of Holland and Turner's test piece, Item 1, and tested at their rate of stressing. In a similar manner Run G strengths can be found for all items. The line BC drawn through these points gives the Run G strength of all widths of test pieces in this range.

For comparison, Holland and Turner's strength found by testing has been plotted on lines 7 to 12. Three of these fall almost exactly on the line CB. The other three are slightly lower.

Their specimens were of two types, namely (a) with edges ground and polished, and (b) with diamond cuts on the tension side. The factor $F_o/F$ in each case is .5. The line ED which is the Run G strength times .5 for these specimens is drawn in and the data are plotted. The circles show their measured strength for the specimens having the diamond marks on the tension side and the X showing their strengths for the specimens having ground and polished edges. The slope of the Run G line is remarkably close to that of the data points of Holland and Turner.

For reference purposes the lines $P_1$ for Preston's

[25] Loc. Cit. (23). See Table III.

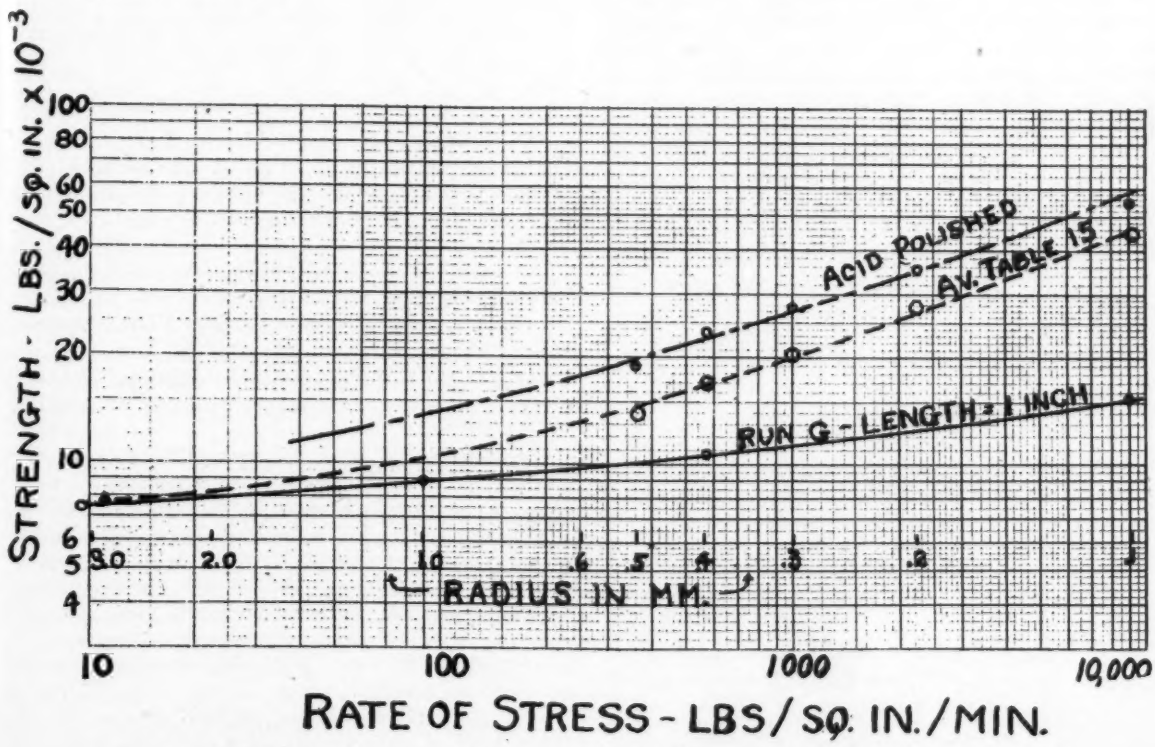



**Fig. 17. Comparison of Gooding's glass fibers with "Run G" indicating orientation.**

¼″ x 2″ x 16″ laths of plate glass and $P_2$ for his ⅛″ x 2″ x 4″ laths of Fourcault glass as reconstructed in the section of this paper dealing with the Strength-Time Relation have been plotted. Their respective Run G strengths have been located. The $F_o/F_1$ factors for these are 1.1 for the plate glass and 1.04 for the Fourcault glass. The diamond marks were on the compression side in both cases.

Black's factor is .75. He had one diamond mark in tension and one in compression.

The use of the area function on laths of glass whose strength has been so greatly reduced that the flaws due to the diamond cut control the stress level does not seem entirely logical. The author has been unable to find any data containing the necessary factors which can be used to study this factor more thoroughly. When a lath of glass is tested by bending as in most of these experiments, the lath assumes an anticlastic curvature. The tension edges are bent downward laterally and this effect causes some stress concentration in the edges. The author has searched for this stress concentration using a Babinet compensator without success in glass test pieces, but it is distinctly visible in the case of celluloid strips. No doubt, the edge stresses are increased in some manner nearly in proportion to the width in glass test pieces of the usual type. The combined effect of width and length of the stressed edges would result in an area function, which, however, would not be strictly similar to that resulting from the flaws in a uniformly stressed fire polished surface.

### Pressure Containers

No satisfactory data regarding bottles are available. J. M. McCormick[26] tested a series of electric lamp bulbs by internal pressure using an unusually well controlled system of testing. The thickness of the glass, the rate of stressing and the shape were all given. These data are plotted on Fig. 16, together with Black's curve and the transposed curve of Run G corresponding to $F_o/F_1 = .78$.

The "A Frosted" bulb does not seem to fit into the data but the "B Frosted" and "B clear" are very nearly parallel to the curve marked "Run G x .78."

The fact that inside frosting increased the strength of the "B" bulbs is proof that the flaw pattern on the *inside* surface of the original bulbs is a factor of strength. In contradiction to this it is often stated that the inside surface of pressure containers is so perfect that it need not be considered in connection with strength.

### Glass Fibers

When the attempt is made to compare the data for the strength of fine fibers with those of "Run G" glass having the same dimensions and tested at the same rate of stressing, it is found that the Run G strength is progressively too small as the diameter is reduced. The divergence is very marked when the fiber diameter is of the order of 0.0001″.

E. G. Gooding[27] made a comprehensive study of the strength of glass fibers. These ranged in size from .1 to .5 mm. radius. They were prepared in a number of special ways and were tested in direct tension. The only factor which is not known is the stressed length. After considering the method of making the specimens, it has been assumed that the stressed length of the "necked down" portion (within 96 per cent of the maximum) is one (1) inch. Gooding's data are given in a series of graphs. The individual shape of the graphs varies so much that it did not seem permissible to pick any one group of data. All of them have, therefore, been averaged except the acid polished curve. The results are given in Table XV, together with the computed rate of stress. Gooding states, "For the continuous loading tests, the lead shot was poured into the bucket at a steady rate until the specimen broke. For the discontinuous loading tests the lead shot was increased by approximately 100 gms. every half minute, the load, of course, never being entirely removed." Since Gooding's results do not show much difference by the two methods, it has been assumed that the steady rate was approximately 200 gms. per minute for all sizes.

TABLE XV. AVERAGE STRENGTH OF GOODING'S FIBERS

| *Gooding's Fig.* | *Radius in mm.* .1 | .2 | .3 | .4 | .5 |
|---|---|---|---|---|---|
| 3 | 30 | 16.5 | 12. | 10.5 | 10. |
| 3A | 43 | 18.6 | 14.5 | 13.5 | 12.2 |
| 5 | ——— | 17. | 12. | 9. | 7. |
| 6 | ——— | 18 | 13.5 | 11.5 | 10. |
| 7 | 27 | 18 | 13 | 11.5 | 9. |
| 8 | 20 | 14.5 | 12 | 10.5 | 10. |
| 9 | 40 | 19. | 15.5 | 12. | |
| 10 | 31 | 21.5 | 14.5 | 14. | |
| 11 | 35 | 22 | 16 | | |
| 12 | 35.2 | 22 | 16.5 | | |
| 13 | 23.7 | 19.6 | 12. | | |
| 14 | 28.5 | 22.2 | 17.5 | 13.5 | |
| Sum | 313.4 | 228.9 | 169.0 | 106. | 58.2 |
| Av. \| Kg mm$^{-2}$ | 31.3 | 19.1 | 14.1 | 11.8 | 9.7 |
| Av. \| Lb in.$^{-2}$ | 44,500 | 27,200 | 20,050 | 16,800 | 13,800 |
| Stress rate | 9010 | 2260 | 1002 | 564 | 362 |

The results have been plotted in Fig. 17 together with the corresponding Run G strengths. The radius of the fibers is plotted along the Rate of Stress abscissa. Gooding's curve for acid polished fibers (his Fig. 15) is also shown.

The noteworthy indication of the graph is that Gooding's fibers have the same strength as Run G glass when his radius approaches that of the Run G rods, namely ⅛″. (3.17 mm.).

The acid polished fibers are approximately 1.35 times as strong as the average of the other fibers at all strength levels and rates.

The divergence of Gooding's strength from the Run G line is believed by the author to be due to the drawing out of the weaknesses inherent in the glass. This seems all the more likely when it is noted that acid polishing, matt etching and other surface treatments did not appreciably change the slope of the strength vs. radius line. The relatively greater strength of Run G glass as compared to bottles and pressure containers is taken as further support to the theory that orientation is an important factor of strength.

(*Continued on page* 147)

[26]McCormick, J. M. "Tests of the Strength of Electric Lamp Bulbs with Special Reference to the Time Factor." Bull. Am. Ceram. Soc., Vol. 15, No. 8, August 1936, p. 268.

[27]E. J. Gooding, "Investigation of the Tensile Strength of Glass." Jo. Soc. Gl. Tech., Vol. XVI, 1932, p. 145.

**Conclusion**

Much of the data on the tensile strength of commercial lime glass can be correlated by taking into account the three major factors, namely (1) the relation between stressed area and the flaw pattern; (2) the character of the flaws which determine the stress level; (3) the rate of stressing.

If the type of test piece varies widely, an additional factor which appears to be a kind of orientation must also be considered.

Various kinds of surface treatment, such as acid polishing, appear to change the level of stress without altering the flaw pattern or otherwise changing the behavior of the glass under test.

Surface compression due to lack of annealing must be corrected for unless this is very small.

The author hopes that the subject matter of this paper may stimulate a research into the measurement of the tensile strength of glass of a more fundamental nature than has been done in the past.

He hopes also that the paper will make clear the necessity for conducting tests under controlled conditions and for recording the conditions with the data and conclusions if the results are published.

The data with which the author has been compelled to work have not been adequate. Many factors have had to be assumed. The range of the experiments have, in most cases, been too small. In particular, the end of the strength-time curve in which impact tests belong is entirely lacking. This end is of great importance and can be easily obtained by the used of a pendulum impact machine.

The question of orientation can be easily studied by testing various sizes of the same kind of glass tubing in two ways, namely, bending, which stresses it axially, and with internal pressure, which stresses it circumferentially. It would be extremely interesting to know whether small hollow fibers drawn from tubing would offer the same increase to bursting pressure that they offer to direct tensile stresses.

If all of the factors of strength can be evaluated it seems likely that the knowledge could be usefully employed in the manufacture of articles of enhanced strength.

*Summary*—The data of Black & Preston have been considered in great detail. It has been shown that the assumption that the breaking effect of a stress is proportional to the time of application of the stress and inversely proportional to the breaking time at that stress is substantially in agreement with the findings of Black & Preston.

A method of applying the above to the solution of various strength-time data has been given.

Certain factors involved in testing have been discussed.

*Acknowledgments*—The author wishes to thank the staff of the Bailey & Sharp Company* for helpful suggestions, particularly Mr. Aaron K. Lyle, who devised the system of computation and did much of the work necessary to separate the Area Function from the data, Mr. F. W. Preston and his associates for helpful criticism, and the Hartford-Empire Co. who supplied the data on Run G glass and otherwise cooperated in the preparation of this paper.

*Now at the Hartford-Empire Company.

**THE GLASS DIVISION PROGRAM**

(*Continued from page* 134)

An interesting question that has been the subject of much debate and conjecture on the part of glassmakers concerns the transmission of heat through molten glass by radiation. It is well that the present study has been done by an independent physicist, probably not prejudiced by too much glass-house opinion. Doctor Havens of the University of Wisconsin has assembled some facts as to the effect of increasing temperature on the absorption of these infra-red radiations and also on the wave lengths which seem to get through to the best advantage. Such data should help to an understanding of what happens in tanks of various depths, as well as in the cooling of gobs of glass and of freshly formed ware.

Badger and Parmelee of the University of Illinois, where some excellent work has been done on surface tension, now take the interesting step of explaining how this property applies to handling glass in the molten condition and to the formation of glass articles. This linking of scientific research with production is exactly what needs to be done, more frequently than it is.

Apparently Shute's paper from the same laboratory will explain how something akin to the stirring of optical glass may be applied to the production of glass in tanks with a view to getting better and more homogeneous glass. Also from the Illinois laboratory is a report of progress on reasearch on cast-iron molds, which is an eminently practical topic hitherto left in the hands of foundrymen and mold makers. The appearance of such studies is definitely to be applauded.

The paper on the design and operation of a window-glass plant for China is of interest as bringing out the particular problems which will be met in such a location, the present day ideas of the Frazier organization on design, and the ideas contributed by Professor Silverman of the University of Pittsburgh. While thought is nowadays directed toward China as the seat of a great deal of political and military disturbance, this paper reminds us that economic and industrial life still goes on in that distracted country under conditions that must be at least extremely interesting.

Hammel and McVay of the University of Alabama have found that a source of great quantities of glass sand exists in that State, constituting a resource that may have a great deal of importance as glass manufacturing spreads into the deep South.

The final Glass Division paper is, most appropriately, one on plastics, by Warner of General Electric Company. These materials, so much like glass and yet so different, are finding so many uses that they are at once a great gift to designers and manufacturers of many and varied small articles, and something of a competitive threat to glass manufacture. The present paper will no doubt bring this whole matter much more into the open and enable a better estimate of the comparative physical properties and utilities of these two great groups of engineering materials.

Altogether, this program is one which no glass man should miss. It will be presented in a city which is probably accessible to more interested persons than any in which the annual meeting has lately been held. A large attendance is expected, and the Glass Division is certainly living up to its reputation as to program.

# CURRENT PRICES OF GLASS-MAKING MATERIALS

**FURNISHED BY PRODUCERS, MANUFACTURERS AND DEALERS**

## Base Materials

| | | Carlots | Less Carlots |
|---|---|---|---|
| Barium carbonate ($BaCO_3$), Crude, (Witherite) 90%, 99% through 200 mesh | ton | 43.00 | 46.00 |
| Barium sulphate, in bags | ton | 19.00 | 24.00 |
| Barium sulphate, glassmaker's, carlots, bulk f. o. b. shipping point | ton | 15.00-16.00 | 18.00 |
| Borax ($Na_2B_4O_7 10H_2O$) | lb. | .... | .... |
| Granulated | In bags, lb. | .0215 | .027 -.0295 |
| Powdered | In bags, lb. | .024 | .0295-.032 |
| Boric acid ($H_3BO_3$) granulated | In bags, lb. | .048 | .054 - .0565 |
| Calcium phosphate ($Ca_3(PO_4)_2$) | lb. | .07 | .07½ |
| Cryolite ($Na_3Al\ F_6$) Natural Greenland (Kryolith) | lb. | .0865 | .0925 |
| Synthetic (Artificial) | lb. | .0825 | .0875 |
| Feldspar— | | | |
| 20 mesh | ton | 11.00-13.25 | |
| 40 mesh | ton | 11.50-13.75 | |
| Granular | ton | 11.75-14.00 | |
| Semi-granular | ton | 11.00-13.25 | |
| L. C. L., (Min. 2 tons) $3.00 per ton additional plus charge for bags | | | |
| Fluorspar ($CaF_2$) domestic, ground, 96-98% (max $SiO_2$, 2½%) | | | |
| Bulk, carloads, f. o. b. mines | ton | 28.00 | .... |
| In bags | ton | 29.60 | 38.00-40.60 |
| Kryolith (see Cryolite) | | | |
| Lead Oxide ($Pb_3O_4$) (red lead) (N. Y.) | lb. | .0735 | .... |
| In 5 Ton lots | lb. | .... | .0775 |
| Less than 5 Tons | lb. | .... | .0825 |
| Lime— | | | |
| Hydrated ($Ca(OH)_2$) (in paper sacks) | ton | 8.50 | 8.50 |
| Burnt ($CaO$) ground, in bulk | ton | 7.00 | .... |
| Burnt, ground, in paper sacks | ton | 9.00 | 9.00 |
| Burnt, ground, in 180 lb. drums | Per drum | 1.60 | 1.70 |
| Kiln Dried ($CaCO_3$) 10x30 mesh | ton | 1.75 | .... |
| Kiln Dried ($CaCO_3$) 16x120 mesh | ton | 1.75 | .... |
| Nepheline Syenite, f. o. b. shipping point | ton | 13.00-14.00 | .... |
| Potassium carbonate— | | | |
| Calcined ($K_2CO_3$) 96-98% | lb. | .065 | .0675 |
| Hydrated 80-85% | lb. | .055 | .0575 |
| Salt cake, glassmakers ($Na_2SO_4$) | ton | 15.00 | 25.00 |
| Soda ash ($Na_2CO_3$) dense, 58%— | | | |
| Bulk | Flat Per 100 lb. | .95 | .... |
| In barrels | Per 100 lb. | 1.35 | .... |
| In bags | Per 100 lb. | 1.10 | .... |
| Sodium nitrate ($NaNO_3$)— | | | |
| Refined (gran.) in bbls. 95% and 97% | Per 100 lb. | .... | 2.50-2.90 |
| Bulk | Per 100 lb. | 1.35 | .... |
| 200 lb. bags | | 1.415 | 1.44 |
| 100 lb. bags | | 1.45 | 1.475 |

## Special Materials

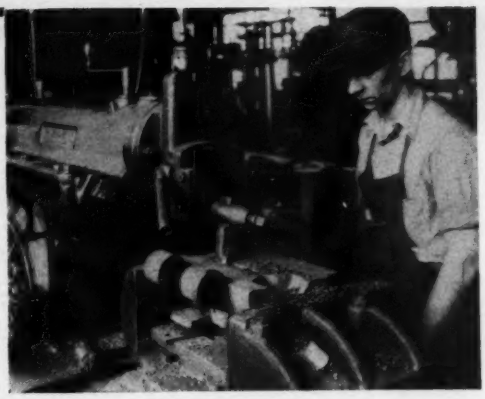
| | | Carlots | Less Carlots |
|---|---|---|---|
| Aluminum hydrate ($Al(OH)_3$) | lb. | .029 | .03½ |
| Aluminum oxide ($Al_2O_3$) | lb. | .04 | .07 |
| Antimony oxide ($Sb_2O_3$) | lb. | .11 | .11¾ |
| Arsenic trioxide ($As_2O_3$) (dense white) 99% | lb. | .03 | .03½ |
| Barium nitrate ($Ba(NO_3)_2$) | lb. | .... | .07¾ |
| Pyrophyllite, (20% $Al_2O_3$) | ton | 9.00 | 12.00 |
| Sodium fluosilicate ($Na_2SiF_6$) | lb. | .035-.04 | .04¼-.05 |
| Tin Oxide ($SnO_2$) in bbls. | lb. | .... | .50 |
| Titanium Oxide (ceramic grade) | | | |
| In bags | lb. | .12¼ | .12½-.13 |
| In barrels | lb. | .12½ | .12¾-.13¼ |
| Zinc Oxide (ZnO) | | | |
| American process, Bags | lb. | .06¼ | .06½ |
| White Seal, 150 lb. bbls. | lb. | .08¼ | .09 |
| Green Seal bags | lb. | .08 | .08¼ |
| Domestic White Seal bags | lb. | .08½ | .08¾ |
| Red Seal, bags | lb. | .07½ | .07¾ |
| Zircon | | | |
| Refined Granular (Milled .01-.02c higher) | | .06½ | .07-.08 |
| Commercial. Gran. (Milled .01¼-.01½ higher) | | .0225 | .0235 |

## Coloring Materials

| | | Carlots | Less Carlots |
|---|---|---|---|
| Barium selenite ($BaSeO_3$) | lb. | .... | 1.40-1.60 |
| (Commercial, 25% Selenium) | lb. | .... | .85 |
| Cadmium sulphide ($CdS$) | lb. | .... | 75-.80 |
| Chromite (99% through 200 mesh) | ton | 35.50 | 40.00 |
| Cerium hydrate— | | | |
| 100 lb. drums and 600 lb. barrels | lb. | .... | .60 |
| Chrome Oxide Green, 400 lb. bbls. | lb. | .... | .22-.26 |
| Cobalt oxide ($Co_2O_3$) | | | |
| In bbls. 350 lbs. or more, | lb. | .... | 1.67 |
| Less than 350 lbs., | lb. | .... | 1.77 |
| Copper oxide— | | | |
| Red ($Cu_2O$) | lb. | .... | .165 |
| Black ($CuO$) | lb. | .... | .16-.17 |
| Black prepared | lb. | .... | .22 |
| Iron Oxide— | | | |
| Red ($Fe_2O_3$) | lb. | .... | .0425-.09 |
| Black ($Fe_3O_4$) | lb. | .04½ | .09 |
| Iron Chromate | lb. | .... | .035-.05 |
| Lead Chromate ($PbCrO_4$) in bbls. | lb. | .... | .145 |
| Manganese, Black Oxide | | | |
| In Paper bags | ton | 47.50 | 50.50-54.50 |
| In Burlap bags | ton | 49.25 | 51.75-56.75 |
| In Casks | ton | 51.50 | 54.00-59.00 |
| Neodymium oxalate, 50 lb. drums | lb. | .... | 3.50 |
| Nickel oxide ($Ni_2O_3$), black | lb. | .... | .35-.40 |
| Nickel monoxide ($NiO$), green | lb. | .... | .35-.37 |
| Potassium bichromate ($K_2Cr_2O_7$)— | | | |
| Crystals | lb | .08¾ | .09-.09¼ |
| Powdered | lb. | .... | .09¼-.09¾ |
| Potassium Chromate ($K_2CrO_4$) 100 lb. kegs | lb. | .... | .27 |
| Powder blue | lb. | .... | .17-.2125 |
| Rare earth hydrate— | | | |
| 100 lb. drums | lb. | .... | .35 |
| 325 lb. barrels | lb. | .... | .30 |
| Selenium (Se) In 100 lb. lots | lb. | .... | 1.75 |
| In lesser quantities | lb. | .... | 1.85 |
| Sodium bichromate ($Na_2Cr_2O_7$) | lb. | .06¾ | .07-.07¼ |
| Sodium chromate ($Na_2CrO_4$) Anhydrous | lb. | .08½ | .08⅜-.08⅝ |
| Sodium selenite ($Na_2SeO_3$) | lb. | .... | 1.50-1.65. |
| Sodium uranate ($Na_2UO_4$) Orange | lb. | .... | 1.75-1.80 |
| Yellow | lb. | .... | 1.75-1.80 |
| Sulphur (S)— | | | |
| Flowers, in bbls. | Per 100 lb. | 3.35 | 3.70-4.10 |
| Flowers, in bags | Per 100 lb. | 3.00 | 3.35-3.75 |
| Flour, heavy, in 250 lb. bbls. | Per 100 lb. | 2.90 | 3.25-3.65 |
| Uranium oxide ($UO_2$) (black, 96% $U_3O_8$) 100 lb. lots. Black | lb. | .... | 2.65-2.75 |
| Yellow orange | lb. | .... | 1.75-1.80 |

## Polishing Materials

| | | Carlots | Less Carlots |
|---|---|---|---|
| Emery, Turkish | lb. | .063 | .07 |
| Pumice Stone, | | | |
| American Ground Italian FFF, FF, F | lb. | .... | .03 |
| 0, 0½, ½, 1. | lb. | .... | .03¾ |
| Putty Powder | lb. | .... | .38-.42 |
| Rotten Stone, (Domestic) | lb. | .... | .02 |
| Rouge, Red | lb. | .... | .14 |
| Black | lb. | .... | .16 |



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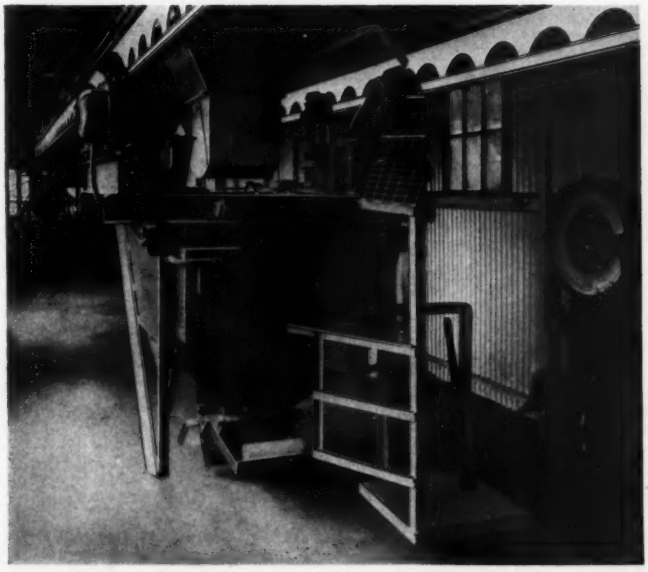

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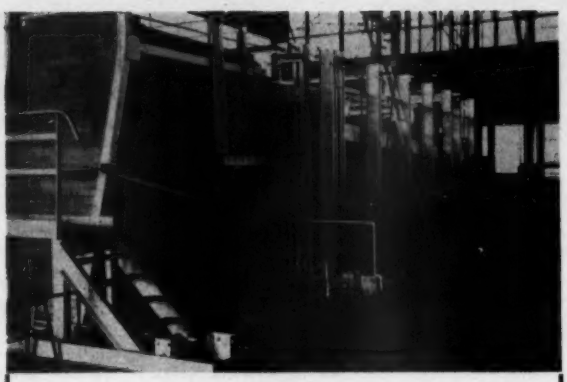

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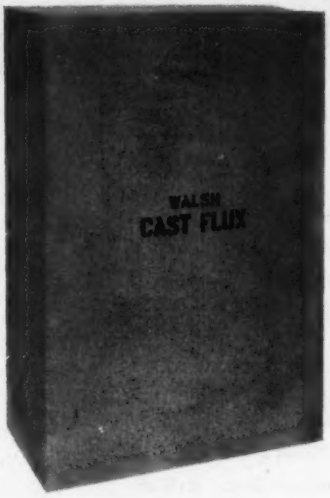


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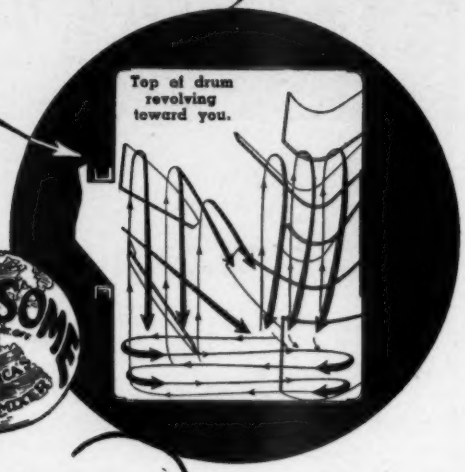

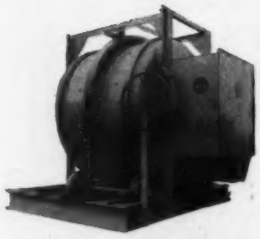

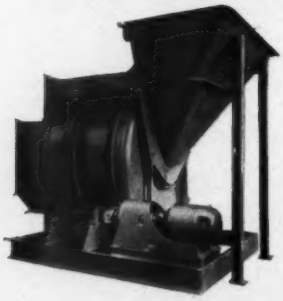

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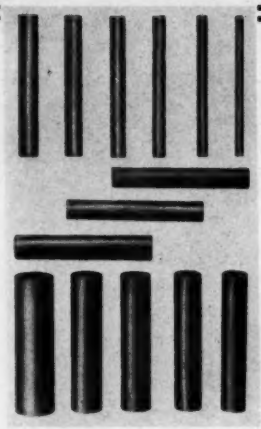

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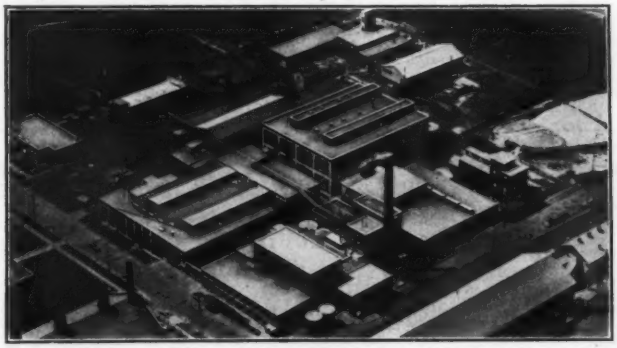

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The PRINCE of GLASS SANDS

The Famous OTTAWA WHITE SAND

## THREE PLANTS TO SERVE YOU

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